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SIMULATION OF GEMINI EXTRAVEHICULAR TASKS BY NEUTRAL-BUOYANCY TECHNIQUES

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SUMMARY

Neutral-buoyancy simulation techniques developed under the direction of the National Aeronautics and Space Administration, Langley Research Center, were applied in a cooperative program with the Manned Spacecraft Center to investigate experimentally the astronaut's extravehicular tasks in the Gemini flight program. The preflight hardware, procedures, modes of performance, and data developed during the neutral-buoyancy tests are described and compared with those pertaining to the extravehicular activities in the Gemini flights. Continuing development of the simulation during this investigation has shown that the techniques are useful in assessing procedures and supporting hardware, obtaining a reasonable estimate of the subject's energy expenditure, and developing realistic time lines in training the astronaut for the extravehicular tasks in space.

INTRODUCTION

Advanced research sponsored by the National Aeronautics and Space Administration has been directed toward development of technology to make orbital and interplanetary flights technically and economically feasible. Human factors and man-system integration research has been underway for several years to understand man's capabilities better in the performance of extravehicular and intravehicular operation in weightless conditions. Understanding the astronaut's capabilities for manual operations in performing locomotion, maintenance, assembly of equipment, cargo transfer, and possible rescue missions is necessary in advancing the technology of manned space missions.

Several years prior to the first extravehicular activities (EVA) by Cosmonaut Alexei Leonov and Astronaut Edward White, simulation techniques were being developed to explore economically the astronaut's EVA capabilities in advance of the actual flights. These techniques included (1) use of the Keplerian trajectory aircraft, (2) gimbal suspension systems, (3) air-bearing devices, and (4) neutral-buoyancy water immersion. All the techniques were useful for zero-g simulation, but only the neutral-buoyancy technique allowed a full unrestricted six-degree-of-freedom operation for long periods of time.

The analogy between manual operation in space and neutral buoyancy was suggested several years ago. It was first used to study the physiological effects of weightlessness as reported in references 1 to 5. Later, this analogy was applied to a study of the external motion performance and biomechanics of subjects in weightless conditions.

Development and use of water-immersion techniques to study ingress and egress from airlocks was initiated by the author (Trout) in 1963. Further development of the techniques was done under a contract during which a number of exploratory tests were made to study ingress and egress problems, extravehicular locomotion, cargo transfer, astronaut rescue, and maintenance tasks using tools. The tests indicated that the simulation technique was suitable for zero-gravity simulation of these operations and would provide a smooth, unrestricted, realistic simulation of most EVA tasks where the velocities were below 1 to 2 ft/sec (0.30 to 0.61 m/sec). Some of the early results are reported in references 6 to 10. During the same time, other researchers were also investigating the neutral-buoyancy technique for zero-gravity simulation (refs. 11 to 13).

After the flight of Gemini IX-A the neutral-buoyancy technique was applied to the examination of EVA tasks on Gemini X and Gemini XI as well as to a postflight examination of the EVA tasks on Gemini IX-A. For the Gemini XII EVA mission the technique was successfully used, for the first time, for the preflight training of the astronaut in his EVA tasks, for the preflight development of entire EVA procedures and equipment, and for the examination and development of a continuous time line for the flight EVA.

The purpose of this paper is to describe the early underwater tests in the Gemini Program and to discuss the problems leading up to the successful application of the technique in support of the Gemini XII EVA mission. Since the final underwater tests and the final procedure and equipment development directly preceding the Gemini XII flight have been and are being documented elsewhere (refs. 14, 15, and 16), this paper will describe only the events and developments in simulation leading up to the successful application to the Gemini Program.

ABBREVIATIONS

AMU	Astronaut Maneuvering Unit
ATDA	Agena Target Docking Adapter
ELSS	Extravehicular Life-Support System

EVA	extravehicular activity
G2C	Gemini model 2 full-pressure suit used for training
G4C	Gemini model 4 full-pressure suit primarily used as actual flight suit
HHMU	Hand-Held Maneuvering Unit (Gemini X)
LRC	Langley Research Center
MSC	Manned Spacecraft Center
QD	quick disconnect for nitrogen line of Hand-Held Maneuvering Unit (Gemini X)

CHRONOLOGY OF GEMINI SIMULATIONS

The extravehicular activities of Astronaut Edward White in the Gemini IV flight demonstrated man's ability to survive outside the spacecraft and the feasibility of performing tasks on the exterior of the vehicle. Extravehicular activities were not attempted again until the Gemini IX-A flight during which the EVA tasks had to be terminated early because Astronaut Eugene Cernan became overheated and exhausted. He also reported other difficulties during the EVA tasks including difficulty in maintaining body attitudes while maneuvering on the handrails, excessive workload buildup while performing relatively simple tasks, inadequate foot restraints at the work station, and loss of traction while working. Because the EVA tasks did not work out as planned, the Manned Spacecraft Center (MSC) began an evaluation of the difficulties. Discussions between the Langley Research Center (LRC) and MSC personnel during June 1966 on the application of the water-immersion simulation techniques for preflight examination of EVA tasks led to arrangements for preflight simulation of Gemini X, XI, and XII EVA tasks and a postflight simulation of the Gemini IX-A as an extension of this contract. This effort was directed jointly by MSC and LRC and supported by personnel, equipment, and technology from both Centers.

On June 30 and July 1, 1966, the first underwater simulation tests of the EVA tasks for Gemini X were performed under this extension by using U.S. Navy Mark IV Modification-0 full-pressure suits. The purpose of the tests was to examine the difficulties encountered in performing the EVA experiments. Motion-picture-film data from these tests were studied by the flight crew prior to the launch on July 18, 1966. Details of these tasks and the simulation are described later in this paper.

During the Gemini X flight, the EVA astronaut successfully retrieved the experiment package from the Agena vehicle, left in orbit from the Gemini VIII mission, but he could not successfully attach another package. The EVA in this mission had to be terminated early to conserve attitude-control fuel.

On July 29, 1966, Astronaut Cernan made a postflight underwater simulation of the Gemini IX-A extravehicular activity tasks by using his G4C pressure suit, after observing similar tests performed by nonastronaut test subjects. The details of these tests are discussed later in the text.

On August 10, 1966, the EVA missions of Gemini XI were simulated by test subjects in G2C pressure suits (ref. 15). Motion-picture films of the simulation were sent to MSC for review by the astronauts prior to their flight. Experiments practiced included attachment of the 100-foot (30.5-m) tether line from the Gemini docking bar to the Agena target vehicle, the D-16 power-tool experiment (ref. 17), and manual work-station experiments at the back of the Gemini service module.

During the Gemini XI flight on September 12 to 15, 1966, Astronaut Richard Gordon completed fastening the tether to the docking bar of the spacecraft during his EVA. Because he became overheated and exhausted, a decision was made to terminate further EVA tasks. However, because of the more extensive EVA planned for Gemini XII, MSC decided to train Astronaut Edwin Aldrin by the neutral-buoyancy technique. On August 22, 1966, simulation was started on the Gemini XII EVA by nonastronaut test subjects in G2C pressure suits. On September 12, 1966, Astronaut Aldrin simulated his contemplated EVA mission. As a result of these tests, a number of procedural and design changes were recommended by Astronaut Aldrin and others associated with the program. These changes were incorporated and reexamined in a set of underwater simulations performed by test subjects on September 14, 1966. Because of the early termination of the EVA tasks on Gemini XI, the entire EVA mission of Gemini XII was closely examined and redirected. Recommendations were made for more extensive evaluation and development of the EVA procedures and hardware and for further training of the astronaut by the neutral-buoyancy simulation techniques. Additional simulations were contracted.

On October 16 and 17, 1966, Astronaut Aldrin simulated and modified EVA procedures and prior design changes for the Gemini XII flight. Biomedical data were taken and a time-line analysis was made of the underwater simulation. Because of the inability to predict EVA performance on previous flights, the tasks were closely examined from the motion-picture data and the biomedical and time-line data were studied to determine the astronaut's energy expenditure, the adequacy of procedures, and the suitability of equipment.

On October 29, 1966, Astronaut Aldrin received his final underwater training in preparation for the Gemini XII flight. The simulation included rehearsal of his EVA procedures with his command pilot, Astronaut James Lovell, who gave commands through a hard-wire communication system to the EVA astronaut. They practiced the EVA tasks exactly as they intended to perform them in space. A medical officer monitored Aldrin's energy expenditure by measuring his heartbeat, breathing rate, and body temperature. Astronaut Aldrin's energy expenditure was controlled by including frequent rest periods.

During the Gemini XII flight on November 13, 1966, Astronaut Aldrin successfully accomplished every assigned EVA task. Reference 14 reported that Astronaut Aldrin's heart rate and time line for the EVA tasks in space were similar to those obtained underwater. Astronaut Aldrin used the zero-gravity procedures in space which he practiced and developed underwater. In every case the practiced procedures were successfully used in completing the EVA tasks in space.

On December 1, 1966, Astronaut Aldrin made a postflight evaluation of the simulation technique. He then examined tasks which he thought he would do differently in space and reexamined the analogy between the underwater simulation and space.

In the following sections of this paper, descriptions are presented of the simulations performed in connection with the Gemini X, IX-A, XI, and XII missions.

GEMINI X SIMULATIONS

Purpose

The neutral-buoyancy simulations of the Gemini X EVA tasks were conducted prior to the flight and were intended to determine problem areas in proposed EVA tasks. The extravehicular tasks simulated included attachment and disengagement of the quick-disconnect (QD) nitrogen line to provide propulsion gas for the Hand-Held Maneuvering Unit (HHMU), manual maneuvering over to retrieve the Experiment S010 Agena Micrometeorite Collection package (ref. 16), and placement of the Experiment T017 Micrometeoroid Erosion panels.

Apparatus

Figure 1 presents a photograph of the mockup for simulation of the QD task consisting of a panel containing a handrail and recess for the quick disconnect and shutoff valve. Because the working interface of the mockup was approximately $1\frac{1}{2}$ by 2 feet (0.46 by 0.61 m), it was installed in a wall section during the simulation tests for the purpose of assessing the effects on the astronaut's performance due to hand and foot contacts with the spacecraft wall. The smaller mockup had previously been used on zero-gravity Keplerian trajectory simulation tests on the aircraft.

Figure 2 presents a photograph of the Agena Target Docking Adapter (ATDA) mockup used in the simulation. Also shown are the S010 and the T017 experiments.

During the neutral-buoyancy simulation the test subject was fitted with a U.S. Navy Mark IV Modification-O full-pressure suit (ref. 8) pressurized to 3.7 psig (25.5 kN/m^2) above the surrounding local water pressure. The suit pressurization system was similar to the one reported in reference 8, except that an air line from the surface was used instead of a storage bottle for supplying pressurization and breathing air to the suit. A mockup of the Extravehicular Life Support System (ELSS) (ref. 15) was mounted on the front torso of the pressure suit. A model of the HHMU was attached to the front of the ELSS by a Velcro pad.

Test Description

Figure 3 presents photographs of the sequence of events on the HHMU quick-disconnect (QD) task. The mockup shown in figure 1 was installed on a larger panel to simulate the sidewall of the spacecraft. Additional handrails were added to aid locomotion. The mockup was placed on the bottom of the swimming pool for the neutral-buoyancy tests.

Frame (a) in figure 3 shows the pressure-suited subject maneuvering onto the mockup by using the handrail. Frame (b) shows the subject threading the HHMU nitrogen line under the handrail. Under these simulated zero-gravity conditions, momentary contacts were made by the feet, hands, and ELSS in order to control body position relative to the mockup. Frame (c) shows the subject maneuvering along the handrail. In this case his legs drifted upward and he is attempting to maneuver his feet down to the surface of the mockup by rotating on the handrail. Frame (d) shows him after he has corrected his body position. However, at this point he was not in a good position to connect the nitrogen line, and, thus, was required to yaw his body to a new position as shown in frame (e).

Frame (e) in figure 3 shows the subject grasping the handrail with his right hand and attempting to attach the nitrogen fitting with his left hand. Being unsuccessful in attaching the quick-disconnect fitting with his left hand, he proceeded to make the connection with his right hand while his body was in a free-floating mode (frame (f)). During this test, no problem was encountered in turning on the valve next to the QD. The test subject practiced the QD task several times until he could perform it successfully in a routine manner.

The second series of neutral-buoyancy simulations for Gemini X included the placement of the T017 experiment on the ATDA and removal of the Experiment S010 Agena Micrometeorite Collection package. A typical order of events during one of these tests is shown in the sequence photographs of figure 4. Frame (a) in figure 4 shows the test subject moving onto the ATDA by grasping the rounded edge of the docking adapter (previously illustrated in fig. 2).

Frame (b) in figure 4 shows the subject moving toward the black Velcro pad on the mockup by grasping the ATDA edge with his hand. After removal of the protective cover over the Velcro pad, the subject is shown attaching the T017 micrometeoroid experiment to the Velcro pad on the side of the vehicle as illustrated in frame (c). The T017 experiment package had been carried on the front of the ELSS by means of a Velcro attachment. Body position was maintained by grasping the removal handle of the S010 experiment while installing the T017 experiment with the right hand. Frame (d) shows him unfolding the T017 experiment on the side of the Agena vehicle, after which the subject maneuvered backward (as illustrated in frame (e)) to begin work on the S010 experiment.

Frame (f) in figure 4 shows the subject grasping the edge of the ATDA with his left hand while removing the retainer plate of the S010 collection panel. At this time he lost his grip on the mockup and began floating away as illustrated in frame (g). Frame (h) shows him recovering from the floating by grasping the mockup with his right hand on the ATDA edge. At this time he is also attaching the S010 panel to the Velcro on his ELSS. Frame (i) shows him moving away from the ATDA after completing his task sequence.

Results and Discussion

Firm conclusions cannot be drawn from the short series of tests for the QD task; however, observations indicate that it was possible to perform this task successfully every time after the development of procedures and with some practice. The sequence photographs of figure 3 illustrate the necessity for providing an interface on the test model similar to that on the flight model, since contacts by the hands and feet are important in determining performance.

The handrail provides a convenient means of locomotion. Radial control about the handrail is somewhat difficult since only a small torque can be applied in this direction, as illustrated in frame (c) in figure 3. Other means of restraint in addition to the handrail might have made the QD task easier to perform.

The major comments noted during the T017 and S010 task simulations were that locomotion and orientation difficulties were encountered because of lack of handholds on the ATDA. The edges of the ATDA were difficult to grasp and retain a hold on during the task performance. In addition, the Velcro patch on the ELSS did not retain the S010 panel securely enough. Even a slight brushing against it caused the panel to break loose and float away. Another comment by the test subject was that the ATDA mockup section of the overall vehicle was not large enough to simulate the interplay between the astronaut and the spacecraft.

Motion pictures of the simulation were shown to Astronauts John Young and Michael Collins prior to the Gemini X flight to point out possible EVA problems. During the Gemini X flight EVA, Astronaut Collins successfully attached the quick disconnect, opened the nitrogen valve, and used the HHMU to transfer to the Agena from Gemini X, which was in a coplanar orbit. The uncontrolled Agena was rolling at a low rate. Astronaut Collins successfully retrieved the S010 experiment but did not attach and unfold the T017 experiment. He had difficulty retaining his grip on the Agena vehicle and completely slipped off and floated away in one instance. The EVA tasks on the Gemini X had to be terminated early to conserve attitude-control fuel for spacecraft maneuvers in preparation for return to earth. In addition, Astronaut Collins indicated that he felt that it was unsafe to return to the ATDA. An additional S010 panel was successfully removed from the Gemini adapter.

Although the neutral-buoyancy simulation tests were not applied toward improving the EVA tasks or hardware of the Gemini X or toward training the astronauts, similar problems of floating away from the worksite and poor maneuverability because of lack of suitable handholds occurred both in space and in the neutral-buoyancy simulation. These tests were the first attempt to obtain a task correlation between the underwater-simulation techniques and weightless conditions in space.

GEMINI IX-A SIMULATIONS

Purpose

During the EVA tasks of the Gemini IX-A flight of June 3 to 6, 1966, Astronaut Cernan became overheated, his tasks became more difficult than anticipated, his helmet visor became fogged, and, as a result, a decision was made to terminate the EVA mission early. As a result of the EVA difficulties, preparations were made for a postflight examination of the Gemini IX-A EVA tasks by using neutral-buoyancy simulation techniques and by having a further evaluation of the validity of the water-immersion simulation by comparing it to the actual flight experience. Astronaut Cernan was assigned to act as both an observer and test subject in these simulations, to reenact the part of the Gemini IX-A EVA tasks which gave difficulty, to evaluate the neutral-buoyancy simulation, and to make comparisons between the simulation and space. Because the Gemini X simulations indicated that more complete mockups were needed for a realistic enactment of the EVA tasks, preparations were made to assemble a full-scale model of the flight vehicle.

Apparatus

The mockup of the flight vehicle was assembled by using the Gemini capsule configuration from the Langley rendezvous docking simulator and the Gemini service-module side panel and the Gemini thermal-curtain-area panel supplied by the Manned Spacecraft Center from the mockups used in weightless tests during the Keplerian trajectory flights of the KC-135 aircraft. The mockup of the full-scale Gemini IX-A flight configuration was assembled in the bottom of the swimming pool (dimensions detailed in ref. 6) in the manner shown in figure 5. The Astronaut Maneuvering Unit (AMU) (ref. 15) was installed in the center of the thermal-curtain area as shown in figure 6. The AMU was a duplicate of the flight version except that it had no propulsion capabilities.

The foot restraints (fig. 7) were duplicates of the flight hardware and consisted of two metal-loop stirrups mounted on a tubular frame. They were provided for the astronaut to stand in while unpacking and donning the AMU.

One Gemini G2C pressure suit was provided by the Manned Spacecraft Center for the nonastronaut test subjects and Astronaut Cernan was to use his G4C training pressure suit during the underwater simulations. One-way communication was provided by underwater speakers in the swimming pool for the nonastronaut test subject, and two-way communication was provided through the helmet of the pressure suit for Astronaut Cernan.

Test Description

Postflight simulations of the Gemini IX-A EVA tasks were performed on July 26 and 27, 1966, by a nonastronaut pressure-suited subject while Astronaut Cernan observed the operation from close range and practiced similar tasks while dressed in a diver's wet suit and using scuba apparatus. After receiving safety instruction in the operation of pressure suits underwater, Astronaut Cernan performed simulation of his EVA tasks underwater in his G4C pressure suit.

Table I presents a list of the EVA tasks which were simulated by Astronaut Cernan, and figure 8 presents a typical photographic sequence of events during the Gemini IX-A simulations. Although other EVA tasks were planned for the Gemini IX-A mission, only the AMU donning task was simulated.

The handrails and foot restraints permitted the subject to maneuver his body into the AMU accurately. Astronaut Cernan was able to don the AMU during the simulation although the task had to be terminated in space because he became overheated. In addition to the AMU donning tasks, Astronaut Cernan made an evaluation of the use of the foot restraints to compare the simulation to his experiences in space. Maneuvers were performed to ascertain his ability to recover from unusual body attitudes, including leaning far backwards and maneuvering with only one foot in the stirrup-type restraints.

Results and Discussion

The result of the postflight simulation of the Gemini IX-A AMU donning task indicated areas of similarity between the water-immersion weightless simulation and actual space. Included among these points of comparison was the fact that Astronaut Cernan had difficulty keeping his feet in the foot restraints (fig. 7) while unpacking and checking out the AMU. This was similar to the problem encountered in space and a factor which contributed to his overheating and eventual termination of the EVA. Another point of correlation was that the exertion required to do the tasks in the water was similar to that in space. Dissimilarities were also apparent from the simulation, including the ability to use both hands freely in the water simulation; whereas in space Astronaut Cernan could not do this. The subjects could also lie back in the foot restraints in the water and recover; whereas in space the spacecraft attitude-control system responding to the disturbances set up on the flight vehicle by the astronaut made the task more difficult. Some trouble was also encountered by Astronaut Cernan when using his helmet underwater in that the helmet faceplate and water together caused distortion which was distracting to him. The nonastronaut test subjects using the G2C suit helmets adjusted to this problem without comment. In addition, Astronaut Cernan indicated that he was uncomfortable when working in an inverted position in the pressurized suit while submerged. The nonastronaut test subjects did not experience discomfort under similar conditions.

Similarities and differences between the neutral-buoyancy simulation and weightless performance of EVA tasks in space could not be firmly established from this one short series of tests. The simulation appeared to be an excellent method of examining task continuity for a series of tasks, of obtaining continuous time lines, and of evaluating EVA problems and hardware. Further evaluations of the simulation and a comparison with space activities was deemed necessary to evaluate its usefulness and future application.

GEMINI XI SIMULATIONS

Purpose

Preflight simulations were used to examine the EVA tasks on the Gemini XI mission. Table II lists the tasks which were simulated by neutral-buoyancy simulation techniques. Each of the tasks was performed individually by a nonastronaut test subject in a pressurized suit, but not in the order in which the tasks were to be performed in flight. The test results were recorded on 16-mm motion-picture film at 24 frames per second, and the sequence of pertinent events was recorded on 35-mm film. The purpose of the tests was to examine difficulties in task performance, evaluate hardware, and obtain task duration.

The Hand-Held Maneuvering Unit (HHMU), as described in reference 15, could not be realistically simulated because of drag limitations of the water-immersion simulation. This conclusion was based on prior unpublished results of neutral-buoyancy tests of a similar unit. A series of space-maintenance tasks was to be examined, including tasks with tools in the thermal-curtain area and the D-16 power-tool experiment (ref. 17) on the side of the service module.

Apparatus

One Gemini G2C pressure suit was provided by MSC for the performance of the tasks. During the tasks the suit was pressurized to 3.5 psig (24.1 kN/m^2) above the surrounding water pressure. Air at approximately 7 ft^3/min (0.011 m^3/sec) is fed through the umbilical line into the torso of the suit for both breathing and pressurization. Suit pressure was controlled by a relief valve in the midtorso which caused a differential pressure of 3.5 to 3.7 psig (24.1 to 25.5 kN/m^2) higher inside the suit than on the outside at that point. Air from the relief-control valve of the suit was discharged directly into the water. Neither two-way voice communication nor biomedical instrumentation was provided during these tasks.

The mockup used for the Gemini XI simulation was installed in the swimming pool and is shown in figure 9. The Gemini capsule used here was the same as that used in the Gemini IX-A simulations; however, the mockup of the service module and the thermal-curtain module were modified.

The side panel behind the capsule was assembled with hardware replicating the Gemini XI flight-vehicle service module. This panel was similar to the one used for zero-g simulation tests by the Gemini flight crew during Keplerian trajectory tests aboard the KC-135 aircraft. The panel contained a retractable handrail, a quick connect-disconnect fitting for the HHMU, the D-16 torqueless power-tool experiment, and the movie-camera mount. The rear of the service module (or thermal-curtain area) contained the EVA work-area mockup. This area had two handrails, one on each side, for astronaut maneuvering, positioning, and locomotion. The lower part of the panel contained two molded foot restraints mounted on a metal platform (fig. 10). The center of the thermal-curtain area contained a circular cover which could be opened by a zipper. Under this cover was a work area containing several experimental tasks requiring the use of tools.

The side panel and the thermal-curtain area of the mockup were supported by a plywood ring and a steel tubing framework. This in turn was mounted on an angle-iron stand for support on the bottom of the pool. The front and rear of the Gemini capsule were mounted on an angle-iron support. Lead weights were provided to hold the mockup in place during the simulation. Only equipment directly related to the EVA experiments was provided. Neutrally buoyant wooden models of the flight cameras were provided for the test. However, the mounting brackets for the cameras were identical to the flight hardware.

Test Description

Figure 11 shows sequence photographs of the major EVA simulated experiments performed on the Gemini XI mission, and table III lists the tasks which were being performed during each of the sequences during the neutral-buoyancy simulation. Starting from a standup position in the Gemini cabin, the subject removed the umbilical line from the storage space and moved it to the outside of the cabin. He next unfolded the handrail from its recessed position on the side of the Gemini service module and looped the nitrogen quick-disconnect line for his HHMU (ref. 15) around the handrail to prevent it from floating off. While still in the standup position in the cabin, he was to mount the motion-picture camera in a bracket on the service module rearward of the cabin. He was then to connect the quick disconnect into the side of the service module and move along the handrail to the work area in the thermal-curtain area. While standing in the foot restraints, the subject had several tasks to perform with tools in the center of the thermal-curtain area.

Upon completion of the tool tasks he was to move along the handrail to the cabin, reload the movie camera and reattach it in a forward-facing position, and then move to the docking nose cone of the Gemini capsule to attach the 100-foot (30.5-m) Agena tether line. These tasks were followed by a set of experimental work tasks with the D-16 power tool on the side panel of the service module.

Results and Discussion

The experimental simulation tests were performed as illustrated in the sequence photographs of figure 11. While performing the EVA standup tasks from the position shown in frame (a), the astronaut drifted out of the cabin as illustrated in frame (b). These tests indicate the need for some attachment to prevent the astronaut from floating out of the cabin during the standup EVA. On subsequent flights a strap was provided on the lower leg of the EVA astronaut's pressure suit so that the command pilot could restrain the EVA astronaut during the standup. As illustrated in frame (b), the movie camera came loose from the Velcro attachment on the ELSS (ref. 15) and floated off. More positive attachments are needed for the attachment of equipment to the astronaut, and a lanyard is needed to prevent the loss of equipment while it is being handled by the astronaut.

The nitrogen line for the HHMU was looped around the handrail and adjusted while the astronaut worked from an unrestrained body position as illustrated in frames (c) and (d) of figure 11. Figure 12 shows some of the apparatus used during these experiments in better detail.

Frame (d) in figure 11 shows the pressure-suited subject practicing the use of the EVA handrail on the side of the service module before connecting the nitrogen line for the HHMU. Handrails provide a relatively easy means of locomotion on the spacecraft; however, some practice is necessary to become proficient in their use in a weightless environment, especially for maintaining and changing body orientation. In this case the pressure-suited subject preferred to be oriented perpendicular to the handrail and moved himself by sliding one hand down the rail and then working the other hand up to it. He did not cross his arms during this procedure. The handrail had an oval cross section which appeared to be of some help in applying radial torque. In this mode, he often contacted the mockup wall panel with his feet to correct body position.

It was found in the neutral-buoyancy simulations of Gemini X and IX-A that full-scale mockups need to be used in the tests because interface contacts of the subject's feet, body, hands, and helmet affect task performance; frame (f) of figure 11 shows the subject contacting the floor of the pool with his feet. These contacts were often inadvertently used by the subject to correct his body position, thus making the simulation unrealistic and masking difficulties which might occur in the performance in space. In this case many of the contacts could have been prevented by rotating the side panel of the service module and the capsule hatches upward several degrees.

Frame (g) of figure 11 shows the test subject preparing the motion-picture camera for remounting just rearward of the spacecraft cabin. In frame (h) he mounts the camera facing the docking cone without realizing that it is facing the wrong direction. Such mistakes are frequently made when the subject is performing a complex series of tasks for the first time in a strange environment. Two-way communication was not used in this series of experiments; therefore, the test subject could not be directed from a checklist by a second person through the one-way communication system. During a long series of tasks duplication of the two-way communication capability can add more realism to task performance, especially in practicing the final procedures for flight EVA tasks.

Frame (l) of figure 11 shows the subject removing the zippered curtain from the experimental tool area at the rear of the service module. The handrails were used by the subject to maneuver into the work position and place his feet in the molded foot restraints. The foot restraints were used for body stabilization and left him free to work with both hands. The foot restraints appeared to give the subject a capability similar to his standup working position under gravity conditions. He was able to perform each of the assigned tasks without difficulty. After successfully completing a number of work tasks with ordinary hand tools in the service area, he closed the zippered cover over the work area and proceeded forward on the spacecraft. The work tasks on the rear of the service module with the use of the foot restraints showed this to be a stable work position for performing tasks which were within reach. These foot restraints (fig. 10) were a considerable improvement over the Gemini IX-A restraints (fig. 7). This system was used to perform various working tasks with one hand and two hands. With the rigid foot restraints he could maneuver from side to side up to about 45° and also forward and rearward as necessary.

The simulation indicates that the pressure-suited subject could carry the various pieces of equipment with him during the EVA tasks; however, each piece of equipment had to be restrained to him with a lanyard to prevent loss. He then proceeded to attach the 100-foot (30.5-m) Agena tether line to the docking bar (frame (n) of fig. 11). One of the experiments on Gemini XI was to tether the Agena target vehicle to the Gemini capsule to study tether dynamics in space. During frames (m) and (n) the pressure-suited subject had problems orienting himself because of a lack of handholds on the forward area of the spacecraft, no place to contact with his feet, and lack of a restraint device to maintain body position. During the installation of the tether line, the subject frequently contacted the pool floor or the support stand with his feet to maintain the position of his body. These experiments indicated that additional handrails or other types of supports are needed to carry out this task effectively. Frame (o) shows the subject unfolding the HHMU while grasping the docking bar.

In frame (p) of figure 11, the subject proceeds to unfold his HHMU. He practices manipulation of the HHMU while floating free. The HHMU model used in these tasks was a wood and plastic mockup and had no propulsion capabilities. However, it was possible to examine the interface of the propulsion unit with the pressure suit while performing other tasks and to determine the ability to retrieve and manipulate the HHMU under neutral gravity-simulated conditions. The test subject was able to unfold, manipulate, and retrieve the HHMU under these conditions.

Frame (q) of figure 11 shows the pressure-suited subject making preparation to use the D-16 power-tool experiment. In this task, the power-tool experiment is mounted in a pullout tray on the lower part of the service-module panel. In order to orient his body into position to open the tool tray, the subject rotates his body with the use of the handrail as shown in frame (r) and proceeds to extend the tray containing the D-16 torqueless power tool. In attempting to use the tool the subject tumbled from his position as shown in frames (s) and (t), thus showing the necessity for some type of restraint device to control body position.

Frames (u) to (x) of figure 11 show the pressure-suited subject again attempting to perform the D-16 power-tool experiment. However, this time, after orienting his body into position, he attached a snaphook (illustrated in fig. 12) from just above his knee to the handrail. After attaching the snaphook, he proceeded to pull out the tool tray (frame (v)) containing the D-16 power tool. With the use of the knee restraint and the one hand on the tool tray, the subject was able to orient himself and carry through the use of the power tool. These experiments consisted of the removal of several bolts to unfasten a plate. The plate was installed in a new position and was tightened with bolts. In addition, the same task was successfully completed with the use of a ratchet wrench.

The leg or knee restraint used during the D-16 power-tool experiment made it possible to complete successfully a task which would otherwise have been unsuccessful. However, the leg restraint is difficult to reach and provides little restraint about the vertical axis of the body and allows the pressure-suited subject to work only within his reach. This simulation does, however, show the need for the development of better restraint systems for performing extravehicular work.

Only one series of EVA neutral-buoyancy simulations was used to examine the tasks for the Gemini XI mission. Information and procedures were recorded on 16-mm film and studied by the flight crew prior to launch.

During the Gemini XI EVA Astronaut Gordon made his egress from the spacecraft cabin and proceeded to attach the 100-foot (30.5-m) tether to the docking bar. In order to compensate for the lack of traction he straddled the nose cone of the Gemini vehicle with his legs as he had done successfully in the zero-g aircraft simulations. He succeeded in attaching the 100-foot (30.5-m) tether but became so overheated that the remainder of the EVA tasks were canceled. Information and procedures observed during the underwater simulations were not used during the flight. No improvements were made in the flight hardware as a result of the simulations except that the camera on his chest pack was deleted.

The extravehicular operations on the Gemini XI indicated that the neutral-buoyancy simulations should not only be performed in greater detail than those performed here but they should be repeated with the incorporation of improvements in task procedures, hardware, and fidelity of the task continuity required on the flight. The results of the simulation and the flight indicate a requirement to obtain information on the subject's energy expenditure if possible from the simulations to prevent a buildup of heat loads during the EVA tasks. During the Gemini XI neutral-buoyancy simulation the task procedures were performed too hastily and no attempt was made to improve either procedures or techniques. In preparation for future flights EVA operational procedures should be more thoroughly developed and the results applied to the flight operation. Lack of handholds for traction on the nose of the Gemini XI vehicle increased the difficulty of performing the task in weightless conditions. Hardware should be thoroughly tested and improved to make each task operationally practical for future missions. Because the subject frequently contacted the pool floor and support stand, the fidelity of the simulation was compromised. Future simulation hardware should be designed with complete mockup and hardware to simulate realistically all interface contacts by the astronaut on a complete task-continuity basis. The neutral-buoyancy simulation permits a continuous examination of task sequences in six degrees of freedom for long periods of time.

The simulation tests reported here are probably of less value because of lack of participation by the EVA astronaut. Experience obtained in the Gemini XI flight program indicated that the astronaut should possibly receive more intensive training by simulation techniques to use efficiently the EVA system provided in a weightless environment. The neutral-buoyancy technique was recommended as a training method. In addition, the Gemini XI program indicated the need for more knowledge about the astronaut's work capabilities, metabolic costs, EVA equipment requirements, and detailed simulations to establish system design and operational procedures for future space vehicles.

EARLY GEMINI XII TRAINING SIMULATIONS

Purpose

Preparations for the Gemini XII program involved, for the first time, preflight EVA training of the astronaut by water-immersion simulation techniques. Neutral-buoyancy simulation tests were conducted between August 22, 1966, and October 29, 1966, and a postflight simulation was made on December 2, 1966. Astronaut Aldrin participated in each series of training simulations, whereas his backup pilot Cernan participated in the last series of simulations prior to the flight.

The simulations between August 22, 1966, and September 14, 1966, were designed primarily to check procedures and train in the task of donning the AMU and the associated manual locomotion about the exterior of the spacecraft.

After the Gemini XI flight on September 12 to 15, 1966, the EVA mission for Gemini XII was modified to include more experiments with restraint systems, the performance of maintenance tasks, and additional locomotion and maneuvering tasks using modified handrails and handholds. These later simulations are described in a subsequent section of this paper entitled "FINAL GEMINI XII TRAINING SIMULATIONS."

Apparatus

Figure 13 shows the mockup used in the Gemini XII simulations on August 22, September 11 and 12, and September 14, 1966. It was similar to the Gemini XI mockup except that the AMU was installed in the center of the thermal-curtain area and the spacecraft hatch area was rotated 180°. The handrails on the side and rear of the Gemini capsule and service module were the same as on the Gemini XI mockup. Modifications to the Gemini capsule included a mockup of the very high frequency antenna and an eye for attachment of the AMU safety line on the capsule nose as shown in figure 14. The mockup was supported by stands at the front and rear of the capsule resting on the floor of the pool as shown in figure 13. The AMU mockup used in the simulations was balanced to neutral buoyancy. The attachment straps and controls on the AMU duplicated those to be used in flight.

The foot restraints used in the first simulation on August 22, 1966, were those shown in figure 15(a). They are shown mounted on a plywood platform at the lower part of the thermal-curtain area. For the simulation on September 12, 1966, the flight-weight support structure was built and a set of refined foot restraints (fig. 15(b)) with the same design principles were used. In order to place his foot in these restraints the astronaut places his foot in a "pigeon-toed" position and rotates the toes of each foot outward. This action clamps both the toes and heel of his foot rigidly in the restraint. This may be compared with the metal-loop stirrups (fig. 7) which were used unsuccessfully on the Gemini IX-A mission. The test subject is shown placing his feet in the restraints in figure 16.

The umbilical standoff was identical to that used on the Gemini XI simulations. It was also used successfully on the Gemini IX-A flight mission and gave no particular problems. Figure 17 shows the tether package and associated hardware which were carried with the AMU and attached to the front of the Gemini XII during the tests.

Test Description

The Gemini XII simulations began on August 22, 1966, when nonastronaut test subjects dressed in G2C pressure suits examined the proposed EVA tasks. The results of these simulations were recorded on 16-mm film, which was studied prior to participation by the EVA astronaut. On September 11 and 12, 1966, Astronaut Aldrin participated in the neutral-buoyancy simulation of the Gemini XII EVA tasks for the first time. On September 14, the EVA tasks were again repeated by nonastronaut test subjects using procedural and design changes recommended by Astronaut Aldrin and other participants.

Nonastronaut participation.- Table IV presents a list of the tasks performed by the nonastronaut test subjects in the early Gemini XII simulation and the accompanying sequence photographs from figure 18. Unlike the Gemini XI simulations, the Gemini XII simulations were carried out in the sequence planned for the flight; and unlike the Gemini IX-A simulations, the entire extravehicular activities were rehearsed as completely as possible.

Astronaut participation.- In preparation for the Gemini XII mission, Astronaut Aldrin was assigned to perform his EVA tasks by using the water-immersion simulation technique. He had previous experience in the use of scuba gear but had not previously operated in a pressurized space suit underwater. Equipped with scuba gear he observed from close range the nonastronaut test subject's performance of the EVA procedure in a pressurized suit.

In order to familiarize himself better with the problems in the simulation, Astronaut Aldrin then performed the entire EVA simulation while wearing a wet suit and scuba gear illustrated in the sequence photographs of figure 19. Frame (b) shows him transferring from the spacecraft to the handrail. Frame (c) shows him traveling along the handrail. In this mode, he traveled with his body extended outward from the mockup with his hands extended over his head. This locomotion was unlike the locomotion by the nonastronaut pressure-suited subject. Frame (d) shows him unfolding the umbilical standoff. Frame (e) shows him preparing the AMU for donning. During this maneuver, he chose to work in the free-floating mode rather than keep his feet in the restraints. Frame (f) shows the astronaut maneuvering into the AMU and practicing the donning of the AMU under simulated weightless conditions. Frames (g) and (h) show him performing the same tasks while in an inverted position. Frame (i) shows the astronaut maneuvering from the inverted position to the corner of the service module. Frames (j) and (k) show him maneuvering to the front of the Gemini configuration. Frame (l) shows him maneuvering about the front of the Gemini configuration. Here he has trouble maintaining orientation and maneuvering about the docking cone because of the lack of handholds which can be used to orient his body. In frames (m) and (n) he is practicing recovery from unusual body attitudes while within reach of the docking alinement pin. Frame (o) shows him returning to the cabin, and frame (p) shows him preparing for cabin ingress.

The scuba-equipped simulation, performed at the request of and by Astronaut Aldrin, served to familiarize him with the underwater simulation and procedures and showed the differences in motion performance imposed by the pressurized suit.

Astronaut Aldrin was then given instruction in the use of the pressure suit underwater and the attendant safety procedures. He then was fitted with his G2C training pressure suit and the ballast as shown in figure 20 in preparation for the test. He was immersed in the pool, and leg and arm weights and other ballast were added to make him neutrally buoyant in all planes.

Table V presents a list of the tasks performed by Astronaut Aldrin as illustrated in the sequence photographs in figure 21. Although figure 21 is similar to figure 18, it was used to show the similarities and differences in performance between the astronaut and nonastronaut test subjects.

Results and Discussion

Comparison of the results shown in figures 18 and 21 indicates very few differences in performance between the nonastronaut test subject and the astronaut. This lack of differences indicates that development of EVA procedures and equipment can be refined to a practical, workable system through simulations by trained test subjects before participation by the astronauts. This conclusion does not rule out recommendations, refinements, and changes by the astronauts but provides an engineering method to test the practicality of procedures and equipment.

The same mode of locomotion along the handrail was used by the astronaut and nonastronaut test subjects when operating in a pressure suit; that is, each operated with the body perpendicular to the handrail by moving one hand down the handrail and then moving the other up to it and repeating the process as he moved along. During the locomotion task they sometimes contacted the floor of the pool indicating that more testing space for the mockup was needed. Lack of handholds made maneuvering around the docking cone of the Gemini particularly difficult. Contacts were sometimes made with the support stand to correct body attitude. This task would probably be even more critical in space with disturbances in the spacecraft set up by the EVA astronaut's motions and the subsequent spacecraft attitude-control corrections. These tests show that improved handholds or restraints are needed to complete similar tasks in space successfully.

The improvements in the foot restraints compared with those in the Gemini IX-A simulations indicate that the more rigid foot restraints give the astronaut a work position similar to a standup work position at earth gravity and permit him to work successfully without loss of body traction. The nonastronaut test subject preferred to work with only one foot in the restraint, whereas the astronaut preferred to have both feet restrained.

Since no propulsion capabilities were provided in the AMU mockup, the subject practiced operating the controls and turning the shutoff valves while in a free-floating mode.

Comparison of figures 18, 19, and 21 shows large differences in performance between the simulation performance of EVA in a diver's wet suit and in a pressurized space suit. The EVA procedures developed by using a diver's wet suit or an unpressurized space suit should be treated as only a crude approximation of the performance in a pressurized suit.

The Gemini XII simulations shown in figure 21 were performed on the same day as the space flight of Gemini XI. Because the EVA mission was not completed on the Gemini XI flight, the results of these simulations were thoroughly analyzed to pinpoint problems which might arise, to familiarize the astronaut with those problems, to show where the equipment was inadequate, and to show where improvements might be made.

Subsequent to these tests, a number of changes were made in the Gemini XII mission. Two additional sets of simulations were made for equipment evaluation and training. These tests showed that (1) the mockups used were inadequate for a realistic simulation of the task and all interfaces with which the astronaut comes in contact must be simulated, (2) additional handholds would be required on the docking nose cone of the spacecraft, and (3) that donning the AMU and manually maneuvering about the spacecraft was very time consuming. Preparation, maneuvering, donning, and doffing would take more than 45 minutes. The AMU would not serve to accomplish a useful mission during the flight.

FINAL GEMINI XII TRAINING SIMULATIONS

Purpose

After the Gemini XI EVA mission, the flight plan for Gemini XII was reexamined and the role of neutral-buoyancy simulation for preflight training and hardware checkout was reevaluated. Subsequently, the flight plan for the Gemini XII EVA was modified, and additional crew training was requested. Simulation tests were set up to evaluate the EVA equipment, develop the EVA time line, train the prime and backup EVA pilots, and obtain baseline biomedical data on the prime EVA pilot. This set of simulations was repeated in several simulation periods during the 4 weeks prior to the Gemini XII flight. The significance relative to the Gemini XII flight is described in reference 15.

Apparatus

Simulations conducted October 14 to December 2, 1966, utilized the mockup shown in figure 22. A mockup of the docking section of the ATDA was added to the forward end of the Gemini capsule. Other major modifications included the addition of a work-task panel in place of the AMU in the center of the thermal-curtain area, a handrail extending from the Gemini to the ATDA, and a work-task area on the ATDA.

The umbilical line to the pressure-suited subject was replaced with one similar to the flight article. It contained instrumentation and communication leads and a line for returning the pressure-suit exhaust gases to the surface of the pool.

Figure 23 shows details of the ATDA mockup and associated hardware. Velcro strips were provided in a U-shaped pattern at the top of the mockup with two single Velcro strips on the lower part of the mockup. The Velcro strips served as places to attach two portable handholds which were carried by the astronaut. Two pip-pin handholds were also carried by the astronaut. They consisted of a pin with a ball-detent locking mechanism which could be plugged into various holes in the ATDA and thermal-curtain work area. Star retainers were provided to prevent the pip-pin handholds from rotating when plugged into these detent holes.

Fixed handholds were provided on the ATDA mockup for the astronaut's manual locomotion. The portable handrail consisted of telescoping tubing which could be extended by the astronaut after docking with the ATDA. One end was fixed to the Gemini vehicle and the other end was fixed to the ATDA during the standup EVA.

The Agena tether clamp was attached to the alinement pin early in the EVA. The clamp attached a 100-foot (30.5-m) tether line between the Gemini capsule and the ATDA for later tether dynamics experiments on separated bodies. The S010 micrometeoroid experiment on the lower docking cone of the ATDA was activated manually by the astronaut. U-bolts were provided on the ATDA docking cone and main body for the attachment of astronaut waist tethers. A work-task panel was provided on the ATDA. It contained provisions to perform torque tasks on bolts and disconnect-connect tasks on a fluid coupling. Although the full-scale ATDA mockup section was incomplete and constructed mainly of wood and sheet metal, it permitted a realistic simulation of most of the proposed EVA tasks. Figure 24 shows the work-task panel in the center of the thermal-curtain area. Foot restraints similar to those shown in figure 15(b) were used in connection with this task panel.

The tool pouch contained a torque wrench to be used later on bolt-removal and tightening tasks. The fixed handholds were rigidly attached to the structure. The pip-pin handholds were similar to the ones used on the ATDA, whereas the portable handholds were fastened to the mockup by Velcro strips. Three different electrical connectors were provided for engagement and disengagement during the EVA. The fluid coupling was of the quick-disconnect type. Various Velcro strips having different holding strengths were provided to check the astronaut's ability to remove, aline, and replace them.

Test Description

Tests performed on October 16 and 17, 1966, allowed Astronaut Aldrin to evaluate the modified EVA procedures and design changes for the Gemini XII flight. Astronaut Aldrin received his final EVA underwater training in preparation for the Gemini XII mission on October 29, 1966.

During the final training the EVA tasks were performed exactly as planned in space. The astronaut's time line for the EVA mission was established, and his energy expenditure rate was controlled. The Gemini XII command pilot, Astronaut Lovell, controlled the simulation from the side of the pool by maintaining voice communication with the EVA astronaut and following the flight checklist. The EVA astronaut's energy expenditure was monitored by measuring his heartbeat rate, breathing rate, and body temperature. The work rate was controlled and a time line established so that the EVA astronaut's heartbeat rate would not exceed 120 beats per minute. Frequent rest periods were established to prevent him from overheating. Continuous motion pictures were made and a voice tape was recorded of the entire operation.

A postflight simulation was conducted on December 1, 1966, to compare the results of the flight with the underwater simulation. Astronaut Aldrin participated in the postflight simulation as the test subject.

Results and Discussion

Figure 25 presents sequence photographs of the significant events during the final EVA training simulation by Astronaut Aldrin for the Gemini XII mission. Table VI presents a description and comments for the sequence photographs in figure 25. The time line for this EVA simulation was over 2 hours. Operations were continuous and no direct assistance was given the EVA astronaut except in one instance when it was necessary to readjust the pressure suit to neutral buoyancy.

Figure 26 shows Astronaut Aldrin maneuvering from the Gemini to the ATDA by means of the portable telescoping handrail. The handrail was very flexible and deflected from 4 to 6 inches when used; however, it provided a convenient means of locomotion between the two configurations. Compared to the Gemini XI where no handrail was provided, this arrangement permitted the astronaut to move to his work area easily with only a small energy expenditure.

Figure 27 shows Astronaut Aldrin repositioning the pip-pin attached to his left waist tether. Two waist tethers were provided which could be attached to the mockup. The tethers allowed him to work in a semifree-floating mode while preventing him from floating away from his worksite. This restraint system allowed him to perform satisfactorily light work tasks not requiring large sustained forces. Momentary contacts on the mockup by the feet and hands were necessary to maintain and correct body position intermittently. During rest periods, the astronaut was able to relax comfortably in the natural shape of the inflated pressure suit in a free-floating mode while attached to the vehicle by the waist tethers. In addition, the waist tethers could be readily plugged into new positions to change worksites.

Figure 28 shows the astronaut tightening a bolt by using a torque wrench while he was attached by the waist tethers. Because this task required sustained force application, it was necessary for him to correct and maintain body position by grasping a handhold with his left hand.

Figure 29 shows the astronaut using the foot restraints to check maneuverability at his worksite in the thermal-curtain area. The foot restraints allowed him to maneuver backward more than 90° and easily recover. In addition, they permitted him to maneuver up to 45° to either side and allowed him to work freely with both hands anywhere on the task panel shown in figure 24. Unlike the waist tether, which was also used at the same worksite, the foot restraints make it possible for the astronaut to apply large sustained forces without adversely affecting his body position. The foot restraints, however, would be more difficult to move from one worksite to another.

The final training simulation indicated that practically all the hardware was suitable for successful completion of the EVA tasks. A notable exception to this was the straps which held the ELSS to the chest. These straps loosened several times during the simulation and were subsequently modified.

The results of the training simulation were examined in detail prior to the flight of Gemini XII. Since the neutral buoyancy had not been used up to this time for preflight training of the astronauts, its value was questionable.

The results of the flight EVA tasks on November 13, 1966, are reviewed in reference 15; therefore, only some of the highlights are discussed in this paper. Astronaut Aldrin successfully completed every EVA task on his flight schedule. The EVA procedures which he developed and practiced in the neutral-buoyancy simulation and training worked equally well in the zero-gravity conditions of space. The hydrodynamic damping, planning forces, and added weights required to achieve neutral buoyancy did not significantly alter the performance modes of the Gemini XII tasks compared with those in space. The overall time line developed in the final underwater training closely approximated that of space with some tasks requiring more time and others requiring less. The continuity of the neutral-buoyancy simulation for an entire sequence of tasks in six degrees of freedom appeared to be of considerable value in developing procedures and establishing time lines for flight EVA.

The full-scale mockup of the flight vehicle and the EVA hardware permitted a high-fidelity simulation not possible with other available simulation systems. The EVA hardware items which proved practical in the underwater simulation worked equally well in space. As a result, where possible, EVA hardware items used in the simulation should be duplicates of those to be used on the flight vehicle, and the mockups should be sufficiently complete to simulate all contacts made by the astronaut.

Reference 14 reports that the astronaut's EVA energy expenditure in space approximated that during the underwater simulations. His heartbeat rate was about 10 percent greater in space. Based on this, the underwater simulation appears to be of value in establishing energy-expenditure rates for EVA tasks; however, additional flight data and more accurate instrumentation may be needed to establish this conclusion.

The EVA work tasks and associated restraint system used showed only minor variations between the simulation and the flight. The performance modes and dynamics were nearly the same in all cases. Because the astronaut's motions were slow and deliberate, the hydrodynamic effects of the water do not noticeably alter the tasks compared to the effects of space.

The use of handrails and handholds for locomotion and maneuvering was very similar underwater and in space. Greater differences were expected in the performance of these tasks because of the higher velocities; however, they did not appear, possibly because the astronaut adhered to the procedures he developed underwater in the simulation. The experiments conducted here indicate that the astronaut should be able to travel to any part of his space vehicle if suitable handrails and holds are provided. Propulsion devices will not be necessary for this task.

Postflight simulation.- The postflight simulation was conducted on December 2, 1966, by Astronaut Aldrin to compare further the results of the flight EVA tasks with the underwater simulation. The preflight training-simulation procedure shown in figure 25 was repeated, except that the same pressure suit used in flight was also used in the underwater simulation. In addition, Astronaut Aldrin examined several tasks which he thought should be performed differently in space but which he had performed according to already practiced procedures. Generally, the postflight simulation further verified the validity and value of the neutral-buoyancy simulation as a means of developing procedures, evaluating the usefulness of hardware, and of astronaut training for the performance of EVA tasks in the weightless conditions of space. In addition to the biomedical data monitored on preflight simulations, oxygen consumption and carbon-dioxide output were also measured in the postflight simulations. The investigators have not yet reported the results of the measurements.

Astronaut comments.- Reference 15 reports the following pilot comments during the Gemini XII postflight EVA debriefings:

> "The underwater (simulation is) . . . a medium that has considerable advantage over the zero-g aircraft in that we can time line things, we can look at the entire flight plan, or whatever the EVA activity might be. It had disadvantages also in that there are buoyancy effects . . . I think these are minor in looking at the whole underwater situation. I would say that it is an excellent training device and we should attempt to make as much use of it as we can . . ."

> "Total time lines are much more valuable to look at in underwater work. Body positioning, I think, is very well simulated in underwater work."

". . . the . . . important thing, I think that we learned . . . is that the motion that you can get in true zero g in (the) foot restraints and the ability to move around is duplicated to an excellent degree by zero-g flight and also by underwater. So, if we can take any situation and expose it to an underwater environment and make sure that the subject has gotten the right buoyancy and the right kind of suit that reproduces the flight suit that he is going to have, we can check out the operation this way rather than trying to take any measurements from the Gemini adapter and extrapolate from there."

The final simulation was a postflight evaluation of the Gemini XII EVA by the pilot. The purpose was to evaluate further and define the fidelity of the simulation technique. The pilot reported that the fidelity of the simulation was good and that underwater simulation was valuable as a method of establishing flight plans, procedures, and operating techniques for EVA. The biomedical monitors concluded that for the Gemini XII EVA, the preflight and postflight biomedical data obtained from the simulation correlated well with similar data obtained from the Gemini XII pilot as he performed the same tasks during flight.

CONCLUDING REMARKS

During the past several years the neutral-buoyancy simulation has been developed into a useful technique for understanding manned extravehicular operations in space. Application and continuing development during the Gemini Program and comparisons with flight data have demonstrated the validity and usefulness of the simulation for development of extravehicular-activity (EVA) procedures and equipment and have shown its value for preflight EVA training of the astronauts.

Application of the neutral-buoyancy technique to the preflight examination of Gemini X tasks was the first attempt to apply the simulation to specific EVA space-flight activities. The mockups used in the simulation permitted only a partial simulation of EVA tasks. Although the tasks were examined by only one nonastronaut test subject in a short series of experiments, the tests indicated that the locomotion, maneuvering, and restraint aids were marginal for completing the tasks. Similar difficulties resulting from lack of traction were encountered by the EVA astronaut during his space flight. Examination of the simulation results both before and after the flight indicated that full-scale mockups should be used and that they should be sufficiently complete so that all body contacts with the mockup can be simulated.

A postflight, but not a preflight, neutral-buoyancy simulation of the Gemini IX-A EVA tasks was performed. For the first time an astronaut in a flight-type pressure suit participated in the simulations by using a full-scale mockup of the Gemini vehicle. Although only the EVA tasks in the thermal-curtain area were simulated, they indicated that the foot restraints provided were inadequate to maintain a firm work position and that the effort and time required to don the AMU were excessive. Similarities and differences were noted between operations in the neutral-buoyancy mode and space; however, further testing and evaluation was deemed necessary to establish the usefulness of the technique.

Preflight simulation of the Gemini XI tasks by a test subject, but not the astronaut, was performed to examine the EVA procedures for possible difficulties. No major changes were made in the flight EVA as a result of the neutral-buoyancy simulation. The results of the simulation indicated that traversal about the forward part of the Gemini vehicle was difficult because of lack of handrails, that the performance of work tasks using the foot restraints was satisfactory, that the torqueless power tool could not be used without restraints, and that performance with the power tool was marginal with the knee restraint. During the space flight the astronaut used different procedures to traverse to the forward part of the Gemini vehicle, but he became overheated and the remaining EVA task was canceled. As a result, the work tasks with tools were not attempted. Because procedures used in the underwater simulation were different from those used in the actual flight EVA, little correlation between the flight EVA and the simulation was obtained. It was then suggested that the neutral-buoyancy simulation be used more extensively for the development of EVA procedures and hardware, for the determination of subject energy expenditure, and for the preflight training of the astronaut in developed EVA procedures.

The simulations on the Gemini XII included, for the first time, training of the astronaut by neutral-buoyancy techniques. During these simulations, procedures were developed for accomplishing each of the EVA tasks, and improvements were made in the supporting hardware to improve manual locomotion, maneuvering, and working on the exterior of the spacecraft. In addition, a continuous time line was developed for the flight EVA tasks, and biomedical instrumentation was incorporated to detect overexertion by the astronaut.

Locomotion procedures about the Gemini exterior were developed and practiced prior to the flight. A portable folding handrail was developed and used for traversal between the Gemini and Agena. Additional handholds were provided on the Agena to provide better maneuvering and locomotion.

Worksite restraint devices were developed and tested, and the astronaut was trained in their use for both the Agena work station and the thermal-curtain work area.

During the Gemini XII flight, the task-performance procedures and supporting hardware developed during the neutral-buoyancy simulations were successfully used to perform the EVA tasks in space. Performance in both modes was similar. The EVA time lines and energy-expenditure measurements during the simulation were reasonable approximations of those measured in flight.

Continuing development of the simulation during this program has shown that the techniques are useful in assessing procedures and supporting hardware, obtaining a reasonable estimate of the subject's energy expenditure, and developing realistic time lines in training the astronaut for the extravehicular tasks in space.

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TABLE I.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 8 DEPICTING GEMINI IX-A NEUTRAL-BUOYANCY SIMULATION

Frame	Task	Comments
(a)	Insert umbilical line in standoff.	Prior to this task, subject moved along handrail on side of spacecraft from cabin.
(b)	Move toward handrail on adapter after adjusting umbilical line in standoff.	Subject required very little exertion to maneuver when motions were slow.
(c)	Grasp handrail and move toward foot stirrups.	Subject was required to prepare AMU for donning. This included inspection, unpacking 100-ft (30.5-m) tether, extending controller, unpacking harness, electrical umbilical, checking propellant pressure, and other tasks preparatory to donning.
(d)	Maneuver into foot stirrups.	After inserting feet in stirrups, subject unpackaged AMU for donning.
(e)	Reinsert foot in stirrup while using handrails.	Subject had problems working with both hands because feet slipped out of stirrups.
(f)	Back into position to don AMU.	Subject had difficulty maneuvering into position.
(g)	Back into position.	Because of awkward maneuvering positions and floating, subject required considerable time to back into AMU.
(h)	Fasten straps across chest to attach AMU.	Straps were difficult to reach and grasp. Mirrors were required to find them.

TABLE II.- CHRONOLOGY OF EVA TASKS ON THE GEMINI XI MISSION

Task number	Task
1	Stand in seat.
2	Feed umbilical line out of hatch.
3	Raise handrail.
4	Position propellant line back to propellant valve. Route under handrail.
5	Install EVA camera in adapter mount.
6	Mount hand-held camera on ELSS.
7	Egress.
8	Unpack spacecraft end of Agena tether.
9	Loop end over docking bar.
10	Unpack tether clamp and install tether clamp on docking bar.
11	Tighten clamp.
12	Remove and jettison clamp handle.
13	Install docking-bar mirror.
14	Return to cockpit.
15	Remove EVA camera for film change.
16	Remount EVA camera facing D-16 power-tool experiment.
17	Plug in HHMU propellant fitting.
18	Perform D-16 power-tool experiment.
19	Remove EVA camera for film change.
20	Remount EVA camera facing rearward.
21	Evaluate handrails.
22	Remove EVA camera for film change.
23	Remount EVA camera facing forward.
24	Move to adapter.

TABLE II.- CHRONOLOGY OF EVA TASKS ON THE GEMINI XI MISSION – Concluded

Task number	Task
25	Insert umbilical line into adapter guard.
26	Photograph adapter.
27	Clear adapter of debris.
28	Attach restraint system.
29	Open tunnel door and put Velcro in place.
30	Connect HHMU to nitrogen line.
31	Unpack HHMU and attach with Velcro to ELSS.
32	Attach camera lanyard to ELSS ring.
33	Unpack Apollo cameras and attach with Velcro to ELSS.
34	Close tunnel door.
35	Remove umbilical line from guide.
36	Open nitrogen valve on adapter.
37	Move to cockpit.
38	Hand camera from ELSS to command pilot.
39	Move to nose of spacecraft.
40	Jettison docking-bar mirror.
41	Evaluate HHMU – omitted because of limitations of the simulation.
42	Return to adapter.
43	Turn off nitrogen shutoff valve.
44	Bleed off propellant in HHMU.
45	Unplug HHMU propellant fitting.
46	Move to spacecraft and stand in seat.
47	Retrieve EVA camera and hand to pilot.

TABLE III.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 11 DEPICTING GEMINI XI NEUTRAL-BUOYANCY SIMULATION

Frame	Task	Comments
(a)	Stand up in EVA.	
(b)	Unfold handrail.	Test subject floated out of cabin while unfolding handrail.
(c)	Secure HHMU line on handrail.	HHMU line was looped around handrail to retain end.
(d)	Traverse handrail.	
(e)	Attach HHMU quick-disconnect lines.	Loop was removed from handrail before making connection.
(f)	Return to spacecraft.	Camera reloading was simulated.
(g)	Manipulate camera.	Motion-picture camera was prepared for remounting just rearward of spacecraft cabin.
(h)	Remount camera.	Camera was remounted. It had been mounted facing wrong direction.
(i)	Traverse handrail.	Subject stopped to recover HHMU which came loose from mounting on ELSS.
(j)	Attach umbilical line.	Life-support umbilical line was attached to standoff at rear of service module.
(k)	Adjust umbilical line.	Umbilical line was adjusted in standoff to permit sufficient length to work in thermal-curtain area.
(l)	Open thermal-curtain work station.	Test subject mounted feet in molded restraints and proceeded to open zippered curtain exposing work tasks.

TABLE III.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 11 DEPICTING GEMINI XI NEUTRAL-BUOYANCY SIMULATION – Concluded

Frame	Task	Comments
(m)	Traverse to nose of spacecraft.	Docking pin was only handhold beyond cabin. Because of lack of surface to contact with feet, subject oriented himself by contacting support stand.
(n)	Attach 100-ft (30.5-m) Agena tether line.	Operation was performed with one hand. Lack of traction on nose of spacecraft made task difficult.
(o)	Unfold HHMU.	HHMU was unfolded with one hand while maintaining body position with other hand.
(p)	Manipulate HHMU.	From a free-floating position, subject practiced manipulation of HHMU.
(q)	Traverse to service module.	
(r)	Orient body.	Rotation of 180° on handrail was required to get to storage rack for D-16 power tool.
(s)	Unpack D-16 power tool.	Upon unpacking D-16, subject was unable to control body position.
(t)	Attempt to use D-16 power tool.	Subject tumbled from worksite.
(u)	Orient body.	Task was started again. Snaphook was attached from knee to handrail as a body restraint.
(v)	Remove D-16 package.	Tool tray was removed from side of service module.
(w)	Prepare D-16 for work tasks.	Safety man exchanged neutrally buoyant tool for one stored in tray.
(x)	Complete work tasks.	Subject successfully completed work tasks and did not tumble from work-site. He had some trouble orienting his body about vertical axis.

TABLE IV.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 18 DEPICTING GEMINI XII NEUTRAL-BUOYANCY SIMULATION BY NONASTRONAUT TEST SUBJECT

Frame	Task	Comments
(a)	Egress from cabin.	
(b)	Position body after egress.	Subject grasped hatch frame to maneuver.
(c)	Transfer to handrail.	Additional handrail would facilitate transfer.
(d)	Maneuver along handrail.	Subject maintained his body perpendicular to handrail.
(e)	Unfold umbilical standoff at corner.	
(f)	Position umbilical line in standoff.	Subject then used handrail in thermal-curtain area to position himself in the foot restraints.
(g)	Inspect and unpack AMU.	Molded foot restraint did not allow feet to slip out, but subject preferred to work with only one shoe in this restraint.
(h)	Turn 180° and back into AMU.	This was one of the more difficult tasks. AMU was then attached by subject to his back with straps across chest.

TABLE IV. - DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 18 DEPICTING GEMINI XII NEUTRAL-BUOYANCY SIMULATION BY NONASTRONAUT TEST SUBJECT – Concluded

Frame	Task	Comments
(i)	Maneuver with AMU on back.	
(j)	Maneuver around corner.	
(k)	Traverse handrail.	Subject preferred to move with his body perpendicular to handrail. This provided him with more control.
(l)	Maneuver about docking cone.	Maneuvering was difficult because of lack of handholds.
(m)	Float free after attaching 100-ft (30.5-m) safety line to nose cone.	Subject practiced use of AMU controls while in free-floating mode.
(n)	Traverse from cabin to thermal-curtain area.	
(o)	Prepare to doff AMU.	Subject had feet inserted firmly in foot restraints for stability while he worked with both hands.
(p)	Doff AMU.	Subject pushed AMU away from spacecraft.

TABLE V.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 21 DEPICTING GEMINI XII NEUTRAL-BUOYANCY SIMULATION BY ASTRONAUT TEST SUBJECT

Frame	Task	Comments
(a)	Egress from cabin.	Subject used hatch frame as handrail to maneuver.
(b)	Maneuver to handrail on side of adapter.	
(c)	Traverse handrail.	Handrail was too close to floor; subject contacted floor with his feet. This compromised simulation.
(d)	Move to corner of adapter section.	
(e)	Attach umbilical line to standoff.	Subject performed entire task from essentially a free-floating mode.
(f)	Prepare AMU for donning.	Astronaut preferred to work with both feet in foot restraints.
(g)	Maneuver into AMU.	Subject prepared to turn and back into AMU.
(h)	Don AMU.	Maneuvering and attaching AMU was the most difficult task in this test series.

TABLE V.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 21 DEPICTING GEMINI XII NEUTRAL-BUOYANCY SIMULATION BY ASTRONAUT TEST SUBJECT – Concluded

Frame	Task	Comments
(i)	Maneuver after release of AMU from attachment.	Umbilical-line management was sometimes a problem.
(j)	Maneuver along side of spacecraft.	Astronaut preferred same body attitude as nonastronaut test subject.
(k)	Maneuver about nose cone.	Lack of handrails made body-attitude control difficult.
(l)	Practice operation of AMU controls from free-floating mode.	No propulsion capabilities were provided in AMU. Controls were operable.
(m)	Proceed to rear of spacecraft.	Manual locomotion was made by grasping hatch frame.
(n)	Prepare to doff AMU.	Feet were held rigidly in foot restraints. Fuel shutoff valve was closed on AMU.
(o)	Doff AMU.	
(p)	Ingress to spacecraft cabin.	

TABLE VI.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 25 DEPICTING GEMINI XII PREFLIGHT NEUTRAL-BUOYANCY TRAINING SIMULATION BY ASTRONAUT TEST SUBJECT

Frame	Task	Comments
(a)	Stand up in EVA.	Very little tendency to float out of cabin was noted. Astronaut restrained himself in cabin by using his feet. Interior of spacecraft was not simulated in these tests. Standup EVA was used as starting point for simulations.
(b)	Remove telescoping handrail from spacecraft hatch.	Handrail was easily removed from clips which held it in place. Turning around in cabin was accomplished mainly by footwork.
(c)	Extend telescoping handrail to full length.	Astronaut had difficulty grasping small telescoped end of handrail with pressurized glove. After small end was extended several inches, remainder of handrail was easily extended. Improvement in design of small end was recommended.
(d)	Attach handrail to retainers at each end.	Handrail was attached easily in retainers at each end, locked in place, and checked. Right-hand end of rail was about 4 ft (1.22 m) beyond astronaut's reach.
(e)	Check tendency to float out of cabin.	Problem of floating out of cabin on previous Gemini flights led to checking this tendency in simulation. Recovery techniques using feet for bracing were practiced. Techniques for solving problem were developed. Slight push with feet caused him to leave cabin.

TABLE VI.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 25 DEPICTING GEMINI XII PREFLIGHT NEUTRAL-BUOYANCY TRAINING SIMULATION BY ASTRONAUT TEST SUBJECT – Continued

Frame	Task	Comments
(f)	Install movie camera facing forward on mounting bracket.	Camera was installed, removed, and reinstalled from standup position in cabin. Before starting task, umbilical lay across astronaut's face plate blocking his vision. He subsequently pushed it over his head.
(g)	Egress from spacecraft cabin.	Astronaut moved purposely out of cabin to free-floating position.
(h)	Remove and reinstall camera.	Camera was more difficult to install from free-floating position. Subject maintained body position by holding to hatch frame of spacecraft. A handhold is recommended to make it easier to control body position.
(i)	Transfer to handrail.	Camera was removed and reinstalled while holding onto handrail with left hand. Task was not difficult even though camera was farther away.
(j)	Maneuver along handrail.	Astronaut moved past spacecraft window. He allowed body to float freely except for grasping handrail.
(k)	Clean spacecraft window.	Astronaut removed cloth from pocket on leg of pressure suit and simulated cleaning spacecraft window. He had difficulty maintaining body position while cleaning window with one hand and grasping handrail with other.

TABLE VI.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 25 DEPICTING GEMINI XII PREFLIGHT NEUTRAL-BUOYANCY TRAINING SIMULATION BY ASTRONAUT TEST SUBJECT – Continued

Frame	Task	Comments
(l)	Traverse handrail to ATDA.	Task was designed to test use of handrail. Movements were slow and deliberate. Handrail deflected 4 to 6 in. on initial use. Astronaut returned to spacecraft cabin to extend umbilical line fully before next task.
(m)	Return to handrail from cabin.	Legs moved vertical to spacecraft before rotation about handrail could be stopped.
(n)	Reverse body position on handrail.	Body was rotated 180°. Movement was deliberate and slow to minimize inertial forces. While traversing handrail, he did not cross his arms.
(o)	Rest.	With the two waist tethers attached to handrail, he rested in free-floating mode for 2 min. Pressure suit assumed natural inflated shape during rest periods as astronaut relaxed. An occasional push with one hand prevented astronaut from drifting into spacecraft.
(p)	Hook up Agena tether line.	With left waist tether attached to handrail, astronaut attached clamp for 100-ft (30.5-m) tether line to docking index bar without difficulty.

TABLE VI.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 25 DEPICTING GEMINI XII PREFLIGHT NEUTRAL-BUOYANCY TRAINING SIMULATION BY ASTRONAUT TEST SUBJECT – Continued

Frame	Task	Comments
(q)	Unpackage S010 experiment.	S010 experiment was mounted on underside of ATDA. Astronaut placed one foot under handrail to maintain body position and prevent his feet from floating away from spacecraft. Body position was difficult to maintain, but mounting of panel was successfully completed.
(r)	Attach restraint harness to new position.	Task served to evaluate dynamics of waist-tether system and to find suitable work positions for performance of tasks in work area. Because of momentary contacts with feet or hands, subject's body kept tether fully extended most of time. Body position was corrected by pushing on surface of spacecraft with hands. ELSS came partly loose, slipped out of place, and had to be refastened.
(s)	Investigate work tasks.	Astronaut investigated several work tasks while restrained by flexible waist tether. Tasks included removal and replacement of Velcro strips, disconnecting and connecting fluid coupling, installation of pip-pins, and evaluation of portable Velcro handhold. Assigned work tasks were carried out without difficulty from tethered floating position.

TABLE VI.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 25 DEPICTING GEMINI XII PREFLIGHT NEUTRAL-BUOYANCY TRAINING SIMULATION BY ASTRONAUT TEST SUBJECT – Continued

Frame	Task	Comments
(t)	Return to spacecraft cabin.	Astronaut disengaged waist tether and returned via handrail to spacecraft cabin. Rest period of 2 min was observed as he stood in cabin. Simulation of removing movie camera from mount, changing film, and remounting movie camera was completed before leaving cabin.
(u)	Transfer to service module.	Astronaut moved out of cabin by using telescoping handrail. He transferred to handrail on side of service module.
(v)	Move along handrail.	Astronaut adjusted umbilical line from being snagged in cabin area.
(w)	Move along handrail.	Movie-camera mockup came loose from chest pack and dangled from tether line. Umbilical line wrapped around astronauts leg.
(x)	Check stability on handrail.	Astronaut tested his ability to control body position. After working with camera for 2 min to reattach it to chest pack, he gave up and let it dangle.
(y)	Move to corner of service module.	Astronaut made visual inspection of thermal-curtain area. Foot was used to correct body position tangent to service module.
(z)	Move around corner.	Umbilical standoff was used as handhold to maneuver around corner.

TABLE VI.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 25 DEPICTING GEMINI XII PREFLIGHT NEUTRAL-BUOYANCY TRAINING SIMULATION BY ASTRONAUT TEST SUBJECT – Continued

Frame	Task	Comments
(aa)	Move to thermal-curtain area.	Astronaut transferred from standoff to handrail in thermal-curtain area.
(ab)	Adjust umbilical line.	Astronaut maintained position with left hand on handrail while umbilical line was maneuvered with right hand. Additional length had to be pulled to thermal-curtain area before installation in standoff. Body position was quite unstable.
(ac)	Fasten umbilical line to standoff.	Umbilical line was easily installed in standoff. Additional length was pulled through standoff for work tasks in thermal-curtain area. Astronaut had trouble maintaining body position during task.
(ad)	Maneuver to vertical position.	Rotation was accomplished with both hands on right handhold. Upon changing to new position, buoyancy of suit changed. Simulation was interrupted for several minutes while suited subject was balanced to neutral buoyancy, after which simulation was continued.
(ae)	Position right foot in foot restraint.	Astronaut used right hand on handrail to adjust body position.
(af)	Position left foot in foot restraint.	Astronaut used both hands on handrail to get left foot in restraint.
(ag)	Install movie camera.	Astronaut installed camera on left side of thermal-curtain area and checked lens setting. Rest period of 2 min followed.

TABLE VI.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 25 DEPICTING GEMINI XII PREFLIGHT NEUTRAL-BUOYANCY TRAINING SIMULATION BY ASTRONAUT TEST SUBJECT – Continued

Frame	Task	Comments
(ah)	Manipulate umbilical line.	Astronaut adjusted umbilical line and checked its position prior to maneuvering tasks. He maneuvered backward 45° and returned by using foot restraints for traction. ELSS came partly loose requiring adjustment of fastening straps.
(ai)	Lean backward in foot restraints.	Astronaut commented that it was easy to lean back to this position.
(aj)	Recover from full backward position.	Astronaut said he could rest easily in this position. Pressure suit exerted only a small force to return him to upright position.
(ak)	Recover to standing position.	There was no problem in returning to standing position, but there was some tendency to oscillate forward and rearward on returning. Umbilical was slightly buoyant.
(al)	Check ability to move to left side.	Astronaut reported his ability to move to any position within radius of his reach. He visually inspected thruster on left side.

TABLE VI.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 25 DEPICTING GEMINI XII PREFLIGHT NEUTRAL-BUOYANCY TRAINING SIMULATION BY ASTRONAUT TEST SUBJECT – *Continued*

Frame	Task	Comments
(am)	Work station tasks with feet in foot restraints.	Astronaut reported that work station was about right height, although work tasks on top of panel were hard to reach. He could remove and replace Velcro strips but had trouble finding wrench in tool pack. Clockwise torque in 3-o'clock position was 300 lb-in. (3.39 N-m) (maximum for wrench). Wrench did not return to zero. Other clockwise torques reported were 300 lb-in. in 12-o'clock position, 300 lb-in. in 9-o'clock position, and 300 lb-in. in 6-o'clock position which was more difficult to attain. Counterclockwise torques were 250 lb-in. (2.83 N-m) in 6-o'clock, 9-o'clock, and 12-o'clock positions and 300 lb-in. in 3-o'clock position. There was no problem controlling body position while in foot restraints. Electrical connector was easily fastened and disconnected. Connector pin was realined and assembled without difficulty. Rest period (2 min) in foot restraints was very comfortable. Subject attempted to cut electrical leads, but cutter would not cut through, possibly because edges were dull. Astronaut commented he lost account of time during simulation. He removed pip-pin handhold from work panel. Star did not lock in place when replaced because of poor design. He tried left-hand one and had same trouble. He tried large torque wrench on center bolts which worked satisfactorily. There was no problem in maintaining body position while in foot restraints. He hooked up waist tethers and removed feet from foot restraints.

TABLE VI.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 25 DEPICTING GEMINI XII PREFLIGHT NEUTRAL-BUOYANCY TRAINING SIMULATION BY ASTRONAUT TEST SUBJECT – Continued

Frame	Task	Comments
(an)	Perform maintenance tasks while using waist tethers.	Repeat tasks performed in foot restraints. Tendency to float up and down while using torque wrench made task more difficult but not impossible. Small parts were hard to retain. Rest period was quite comfortable. In Velcro removal and replacement task, a handhold would be helpful but not essential. Fluid disconnect and connect task required push against tether to obtain traction. Subject's head occasionally drifted into mockup while working. Pip-pin task was satisfactory. Small manipulative tasks were performed. There was a 2-min rest period with feet in foot restraints and waist tethers attached. ELSS came loose on chest during work tasks and had to be refastened. He removed waist tether and pip-pin handholds attached to chest pack, which would not stay in place on Velcro. He removed movie camera from mount and attached to chest pack.
(ao)	Work with one foot restrained.	Ability to maneuver and recover with right foot in restraint and left foot free was tried.
(ap)	End of tasks in thermal-curtain area.	Foot was removed from restraint. Astronaut maneuvered umbilical and detached it from corner standoff.

TABLE VI.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 25 DEPICTING GEMINI XII PREFLIGHT NEUTRAL-BUOYANCY TRAINING SIMULATION BY ASTRONAUT TEST SUBJECT – Continued

Frame	Task	Comments
(aq)	Maneuver to side of service module.	Astronaut used umbilical standoff as handhold.
(ar)	Move to handrail.	Astronaut preferred to move to his right, perpendicular to handrail.
(as)	Transfer from service module to Gemini capsule.	
(at)	Return camera to cabin.	Camera used in thermal-curtain area was returned to cabin.
(au)	Install forward-facing movie camera.	He could not attach camera with left hand and moved to new position.
(av)	Install camera.	Astronaut moved to inverted position with left hand on handrail so he could install camera with right hand. He was successful this time.
(aw)	Rest.	
(ax)	Rest.	He moved slowly along handrail while resting.
(ay)	Rest.	He continued to move along handrail.
(az)	Start to turn around.	He rotated body with his two arms wide apart on handrail.
(ba)	Turn around.	He unknowingly caught umbilical line with left leg.

TABLE VI.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 25 DEPICTING GEMINI XII PREFLIGHT NEUTRAL-BUOYANCY TRAINING SIMULATION BY ASTRONAUT TEST SUBJECT – Continued

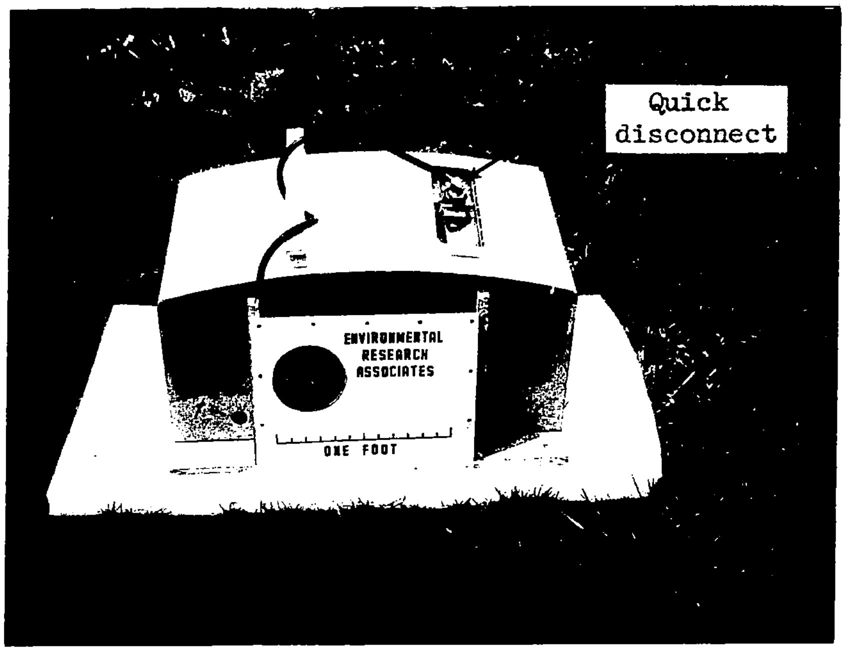
Frame	Task	Comments
(bb)	Fasten waist tether.	He connected waist tether to pip-pin attachments. He tried pip-pin handholds, but they were not satisfactory, because they could not be prevented from rotating. He had trouble finding right waist tether because poor tactility in pressure suit. He had observer tell him where to reach. Velcro-attached handhold was installed. It was usable but unstable. He tested area of movement on waist tethers.
(bc)	Move to new position.	Astronaut reinstalled waist tethers in new positions.
(bd)	Reposition umbilical line.	Umbilical line interfered with work area and was trapped between his legs. It took about 2 min to change its position. He could not see where it was routed past his legs because pressure suit was difficult to bend far enough at the knee to kick umbilical line out of way.
(be)	Move waist tether to new position.	With umbilical line out of way, he continued with tasks.
(bf)	Test new tether position.	
(bg)	Take 2-min rest period.	Astronaut occasionally pushed with hand or foot to maintain relaxed free-floating condition during rest period. Position was maintained better during rest period if tethers were spaced far apart.

TABLE VI.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 25 DEPICTING GEMINI XII PREFLIGHT NEUTRAL-BUOYANCY TRAINING SIMULATION BY ASTRONAUT TEST SUBJECT – Continued

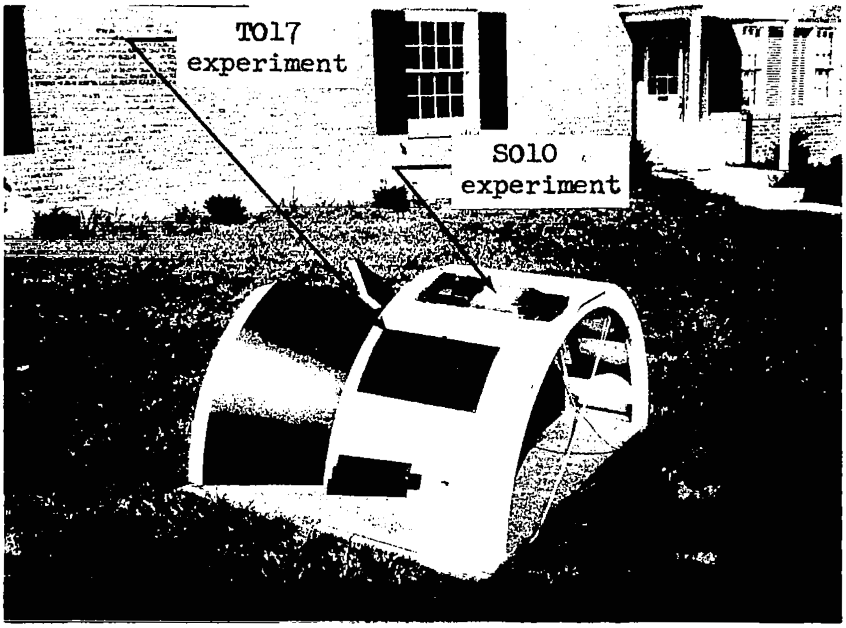
Frame	Task	Comments
(bh)	Reposition pip-pins.	He shortened tether straps to be closer to work station.
(bi)	Check drift from new tether position.	
(bj)	Check tendency to twist on tethers.	There was some tendency to twist if tethers were spaced close together.
(bk)	Reposition pip-pin at work station.	
(bl)	Change tether-attachment point.	
(bm)	Take 2-min rest period.	Astronaut was very quiet – probably getting tired or bored.
(bn)	Do maintenance tasks.	He used torque wrench on bolts. There was only small tendency for body position to change when torque was applied intermittently. He broke stud off with wrench.
(bo)	Continue maintenance tasks.	He released right waist tether and left other still fastened. Pipe fitting connected and disconnected satisfactorily. Fluid connector disconnected and connected satisfactorily.
(bp)	Transfer to spacecraft.	He moved along handrail. There was some entanglement with umbilical line.
(bq)	Turn on handrail.	
(br)	Maneuver with one hand on handrail.	There was additional entanglement with umbilical line.

TABLE VI.- DESCRIPTION OF SEQUENCE PHOTOGRAPHS OF FIGURE 25 DEPICTING GEMINI XII PREFLIGHT NEUTRAL-BUOYANCY TRAINING SIMULATION BY ASTRONAUT TEST SUBJECT – Concluded

Frame	Task	Comments
(bs)	Try axial position about handrail.	
(bt)	Turn on handrail by using one hand.	
(bu)	Move to cabin.	
(bv)	Turn toward cabin.	
(bw)	Enter cabin.	No attempt was made to remove umbilical line from between legs however it would have been a problem during flight EVA.
(bx)	Retrieve movie camera.	Camera was cleared of wires and moved into cabin.
(by)	Turn in cabin.	
(bz)	Remove portable handrail.	Handrail was discarded.
(ca)	Manage umbilical line.	ELSS flapped around and caused repeated tightening of straps. Improvement was needed for flight hardware. Managing umbilical line was reasonably easy task.
(cb)	Store umbilical line in spacecraft cabin.	He checked hatch seal for umbilical-line interference.

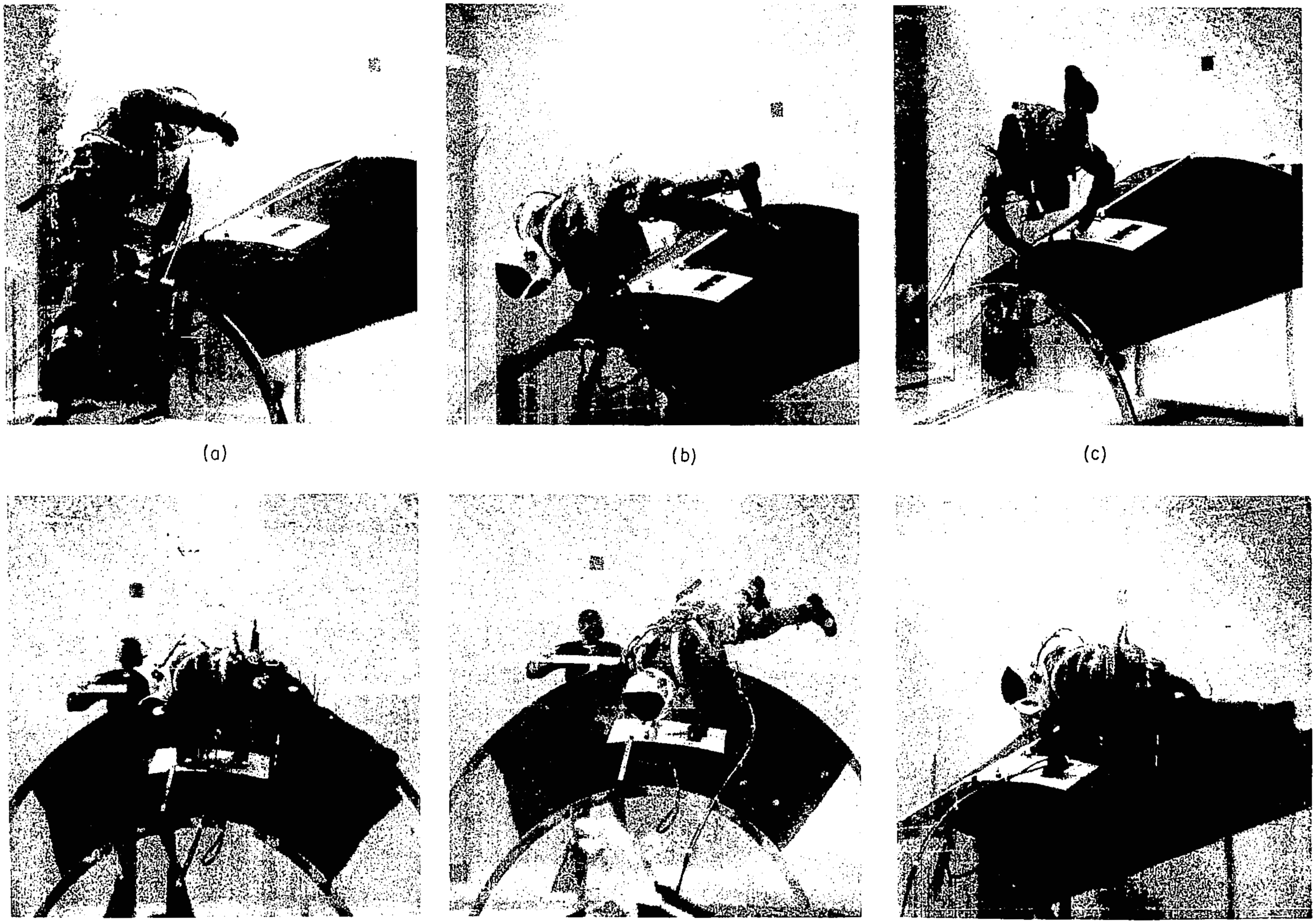


L-69-1262
Figure 1.- Photograph of mockup for simulation of the quick-disconnect (QD) task for the HHMU.



L-69-1263

Figure 2.- Photograph of the ATDA mockup with the Experiment S010 Agena Micrometeorite Collection package and Experiment T017 Micrometeoroid Erosion panel.

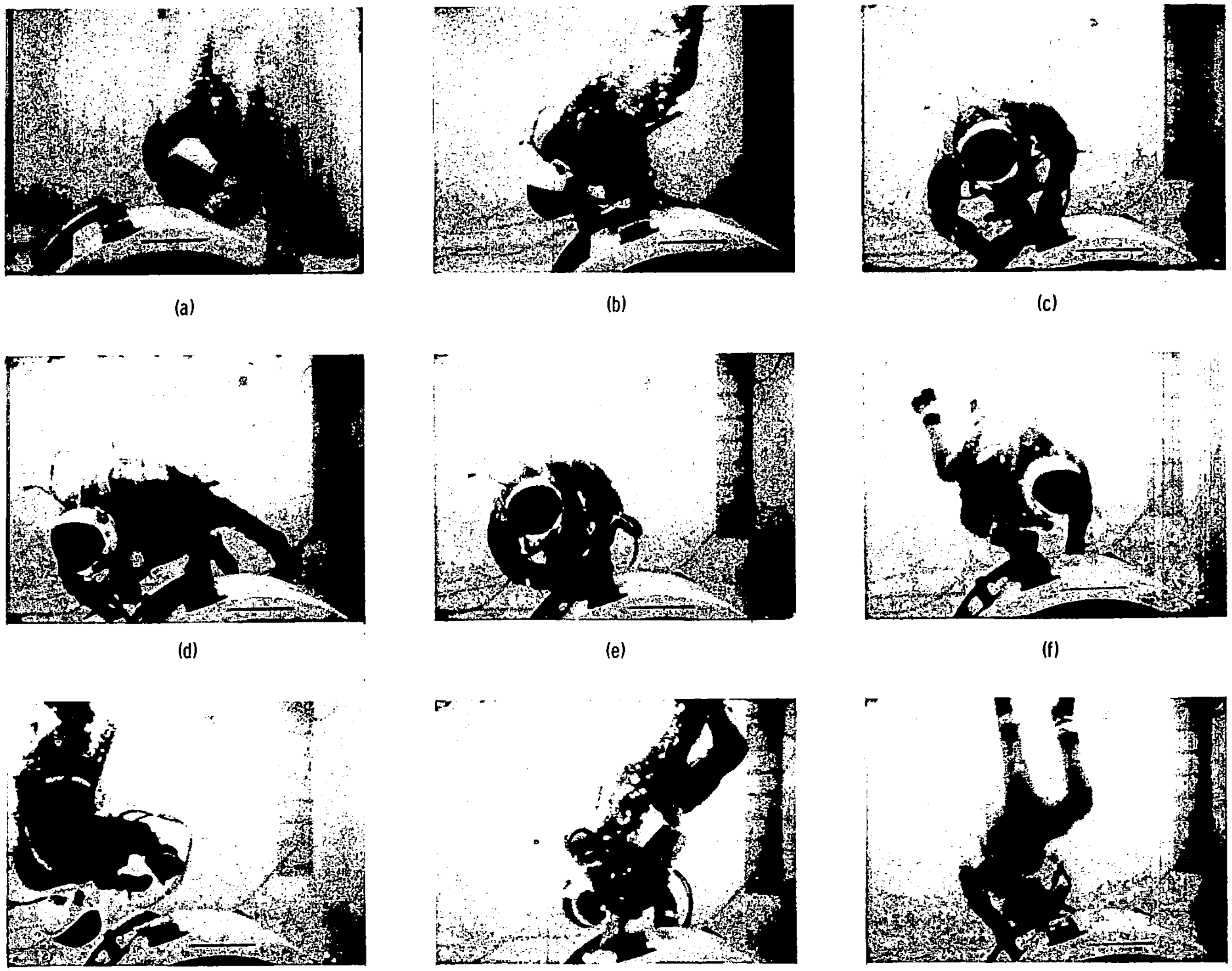


(a) (b) (c)

(d) (e) (f)

Figure 3.- Sequence photographs of performance of the HHMU quick-disconnect task.

L-69-1264



(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

Figure 4.- Sequence photographs of the simulation of the S010 and T017 tasks. L-69-1265

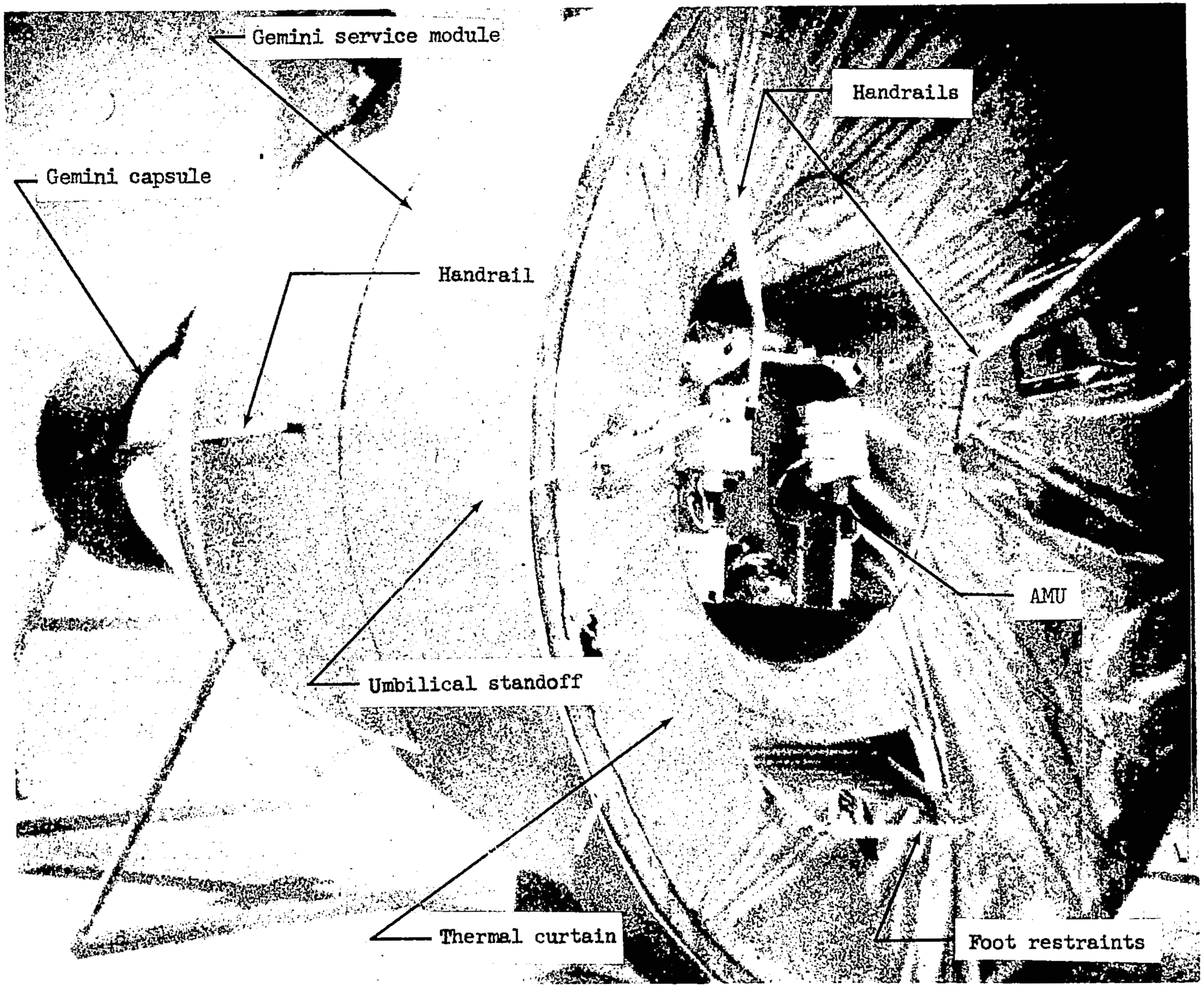


Figure 5.- Gemini IX-A mockup used in neutral-buoyancy tests. L-69-1266

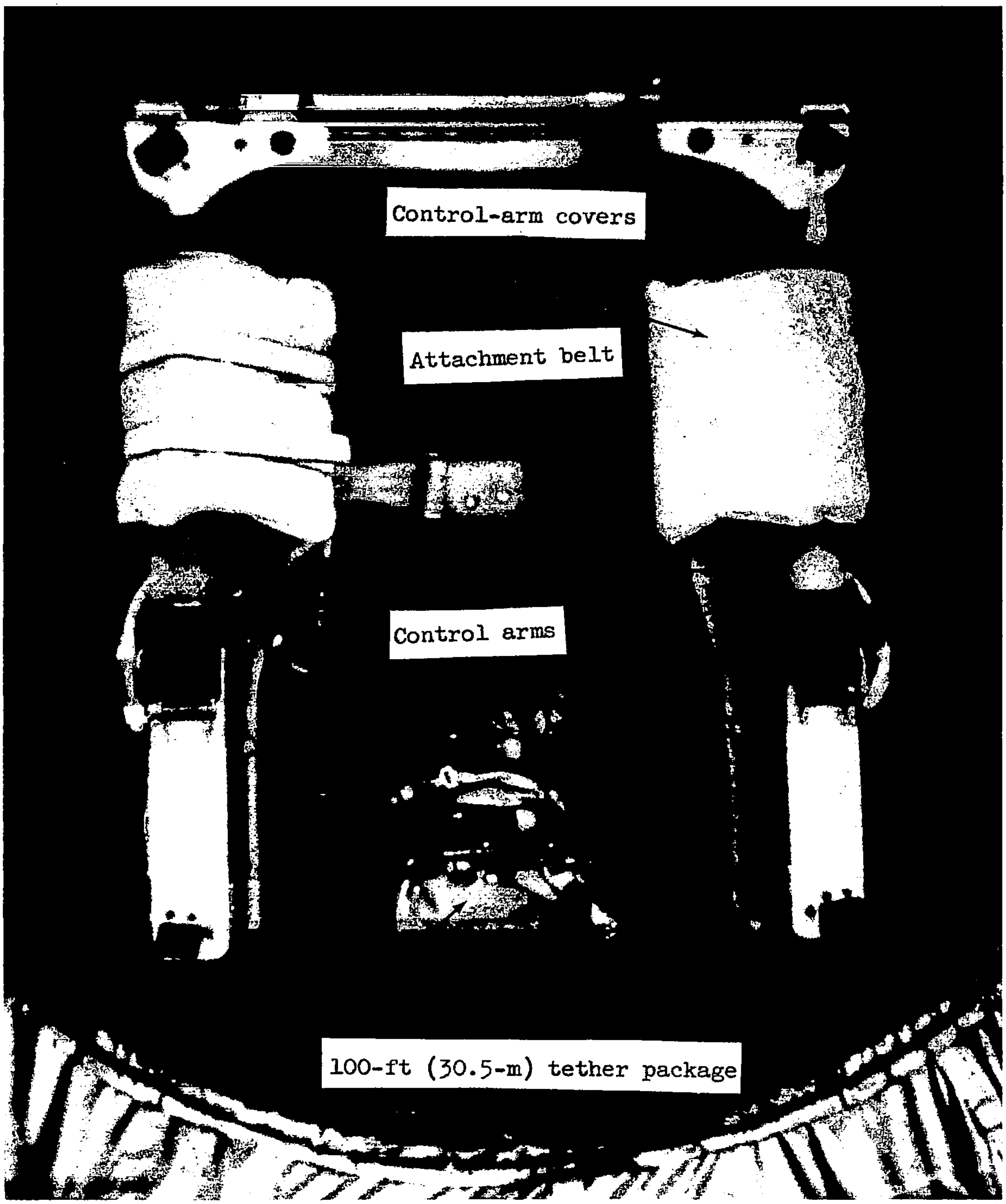


Figure 6.- The AMU mounted in center of the service module. L-69-1267

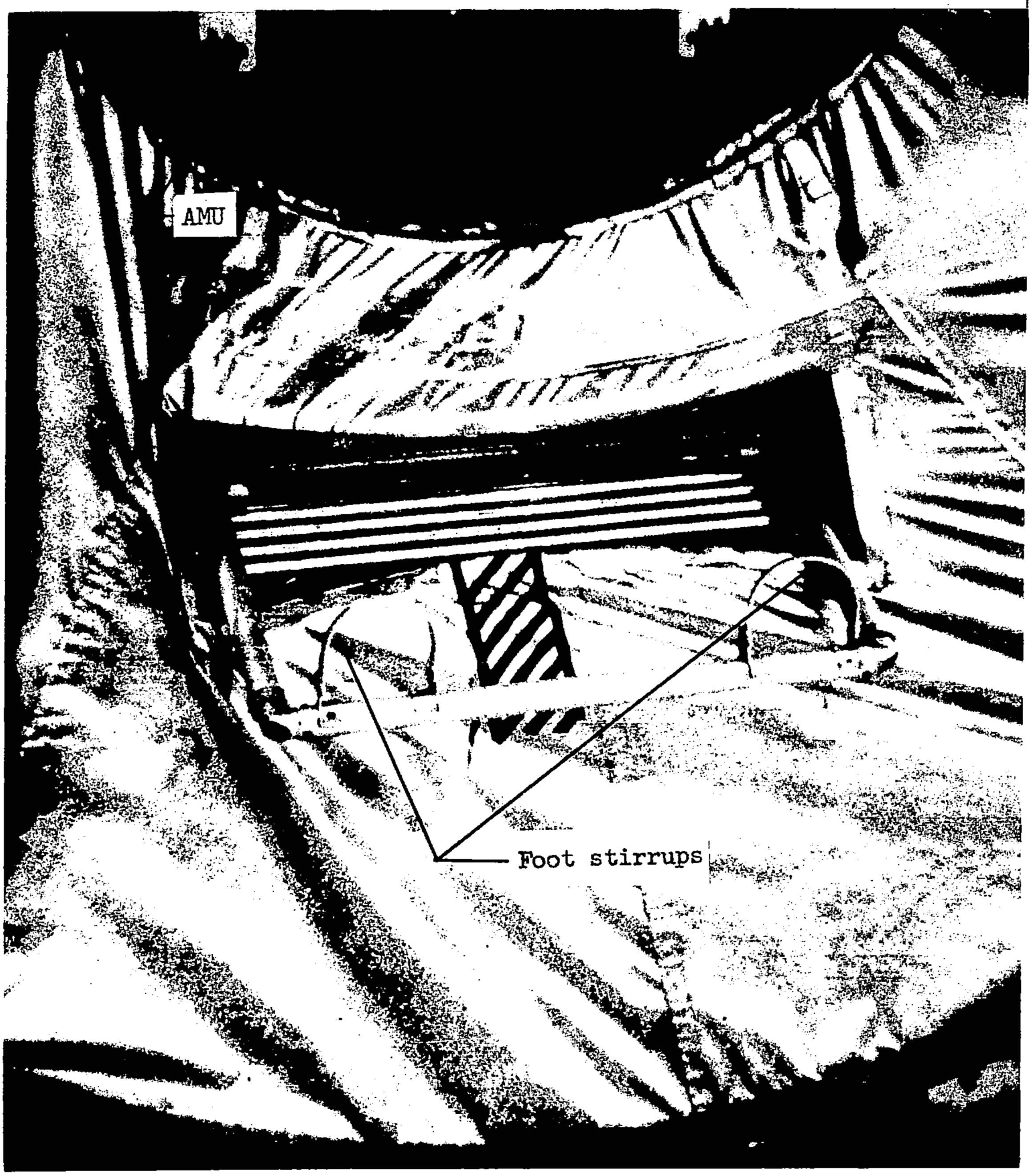
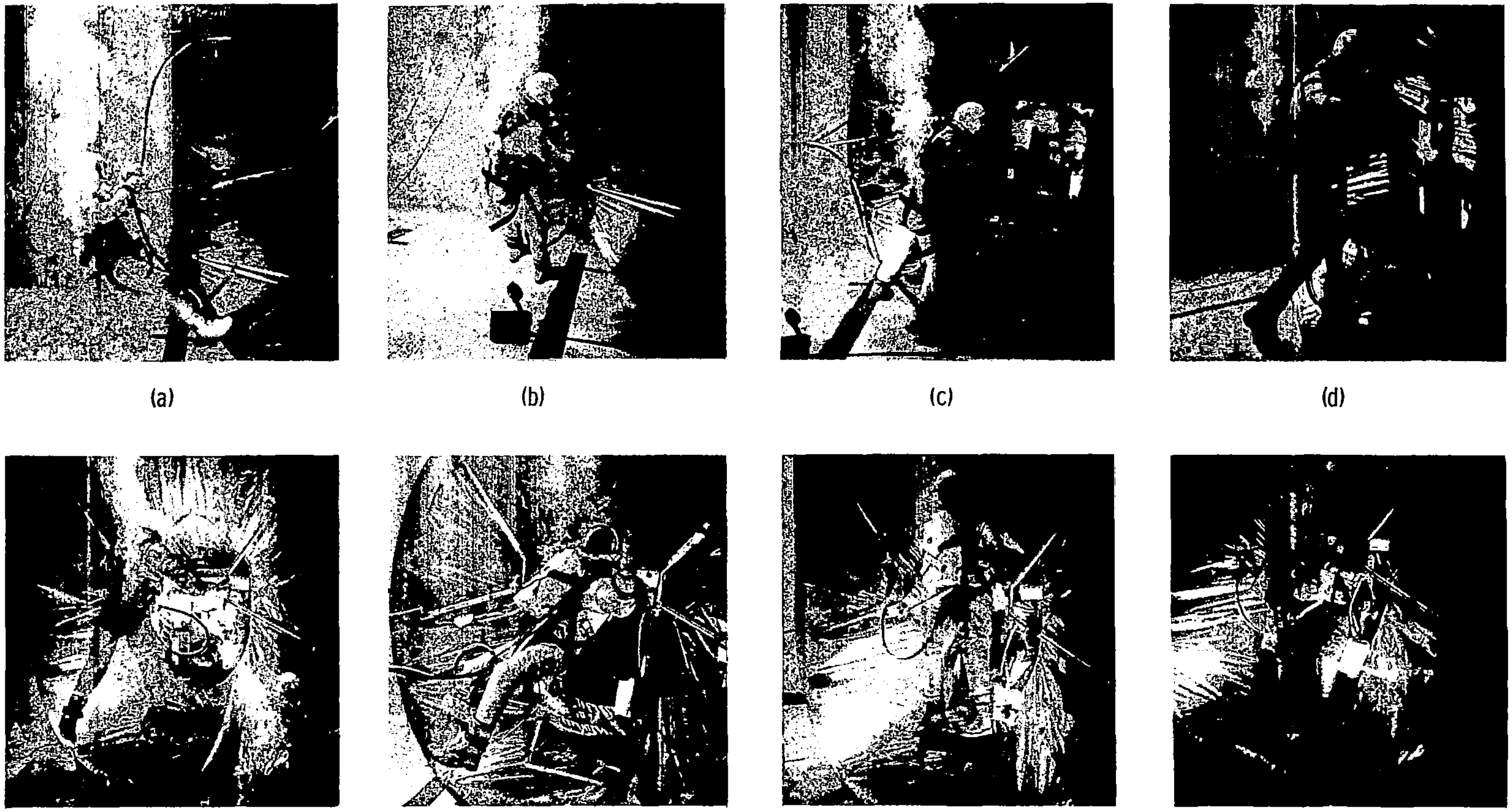


Figure 7.- Foot restraints for Gemini XI-A simulations. L-69-1268



(a) (b) (c) (d)

(e) (f) (g) (h)

L-69-1269

Figure 8.- Sequence photographs of the pressure-suited subject performing self-locomotion and manipulative tasks during the Gemini IX-A water-immersion simulations. (See table I for description.)

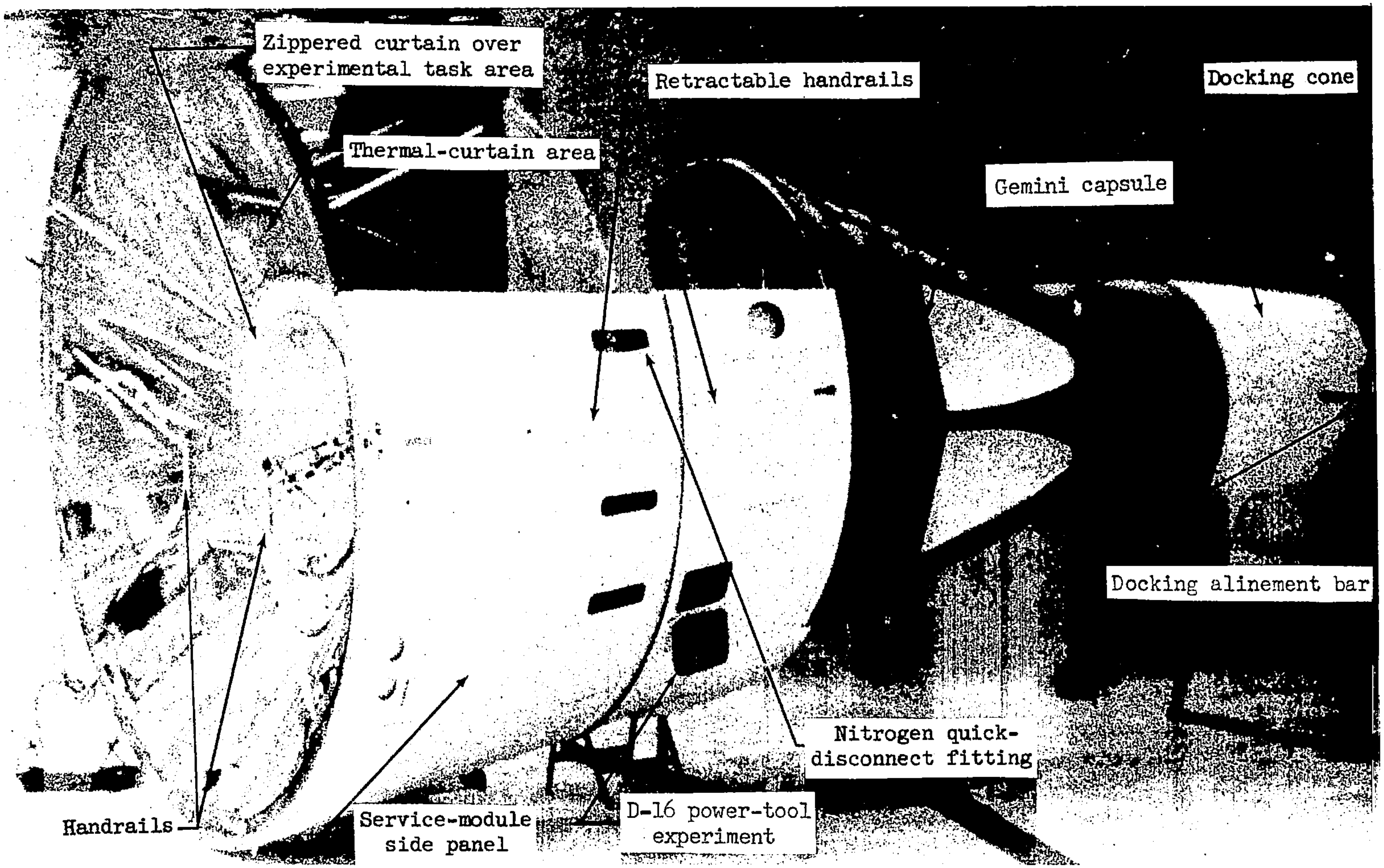


Figure 9.- Photograph of Gemini XI mockup used in the neutral-buoyancy simulations.

L-69-1270

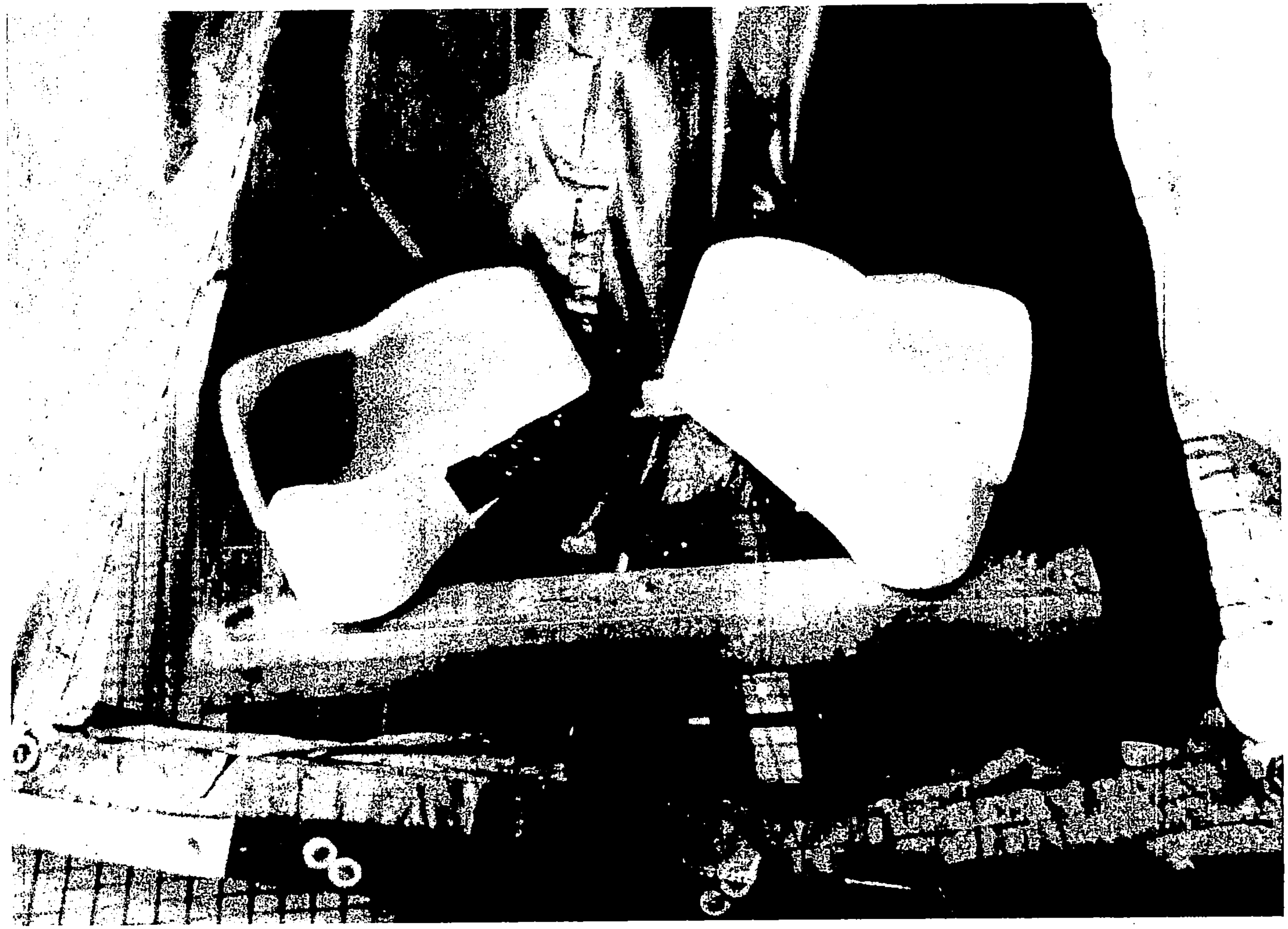
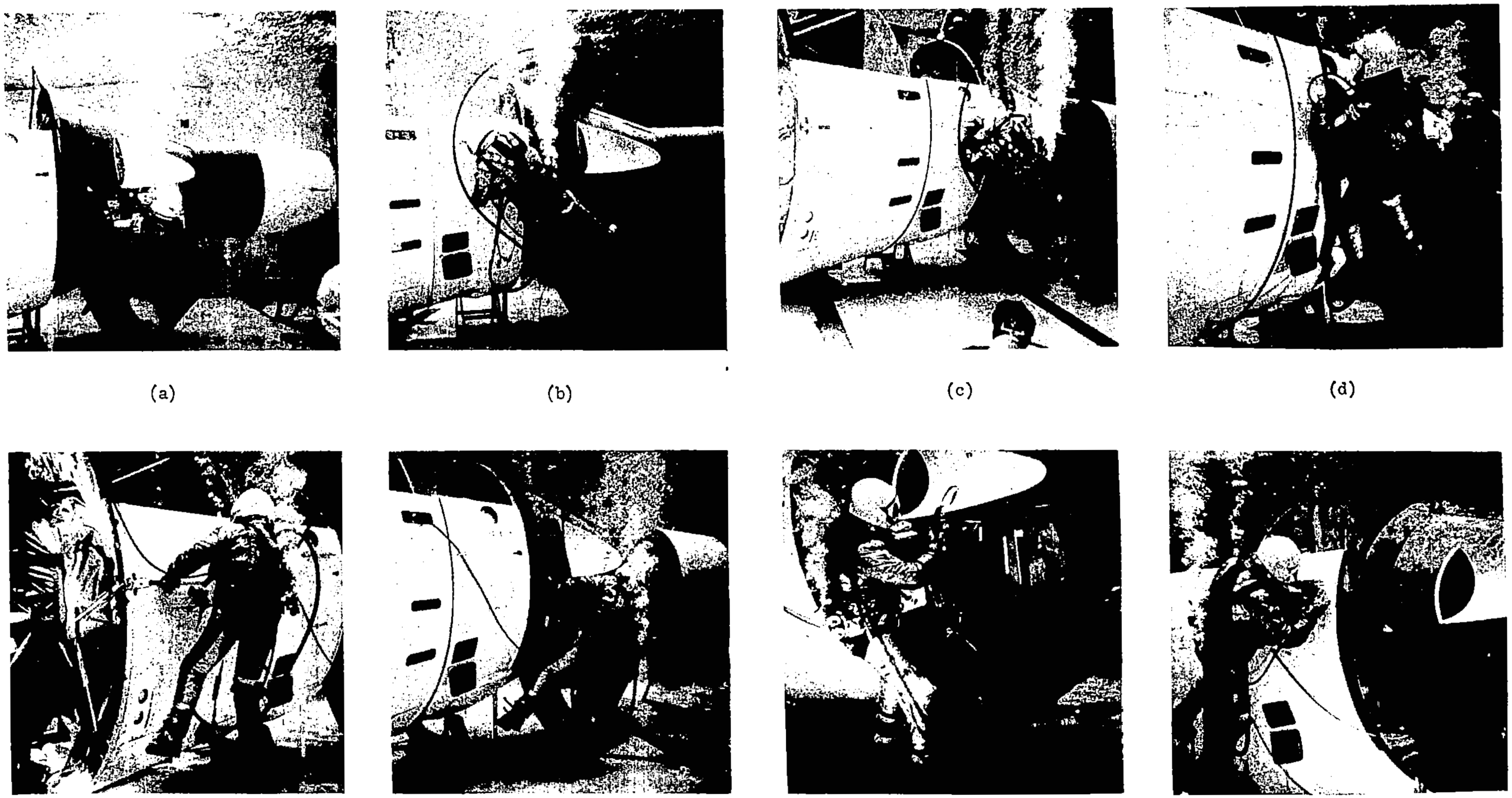


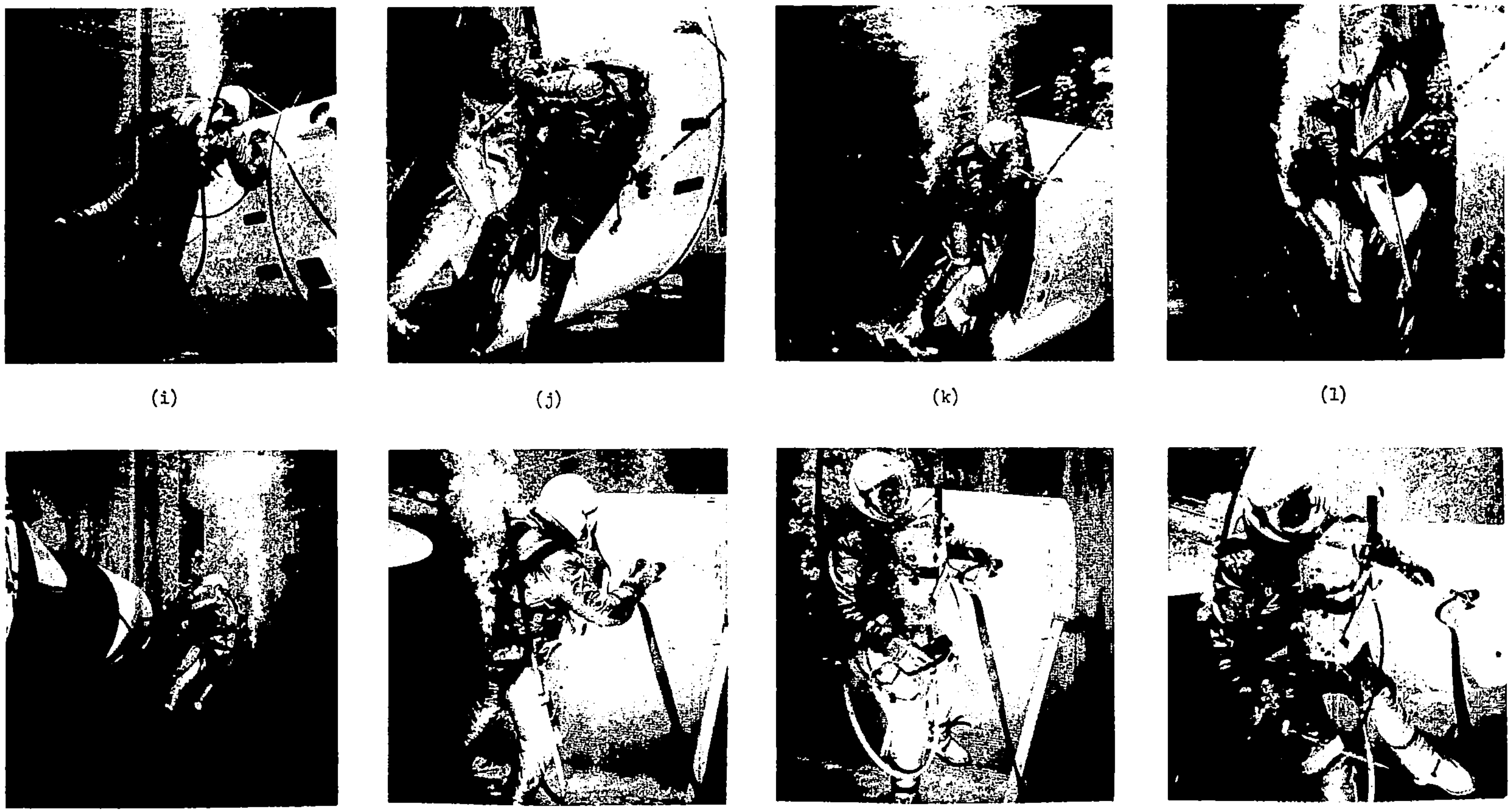
Figure 10.- Molded foot restraints for Gemini XI simulations. L-69-1271



(a) (b) (c) (d)

(e) (f) (g) (h)

Figure 11.- Sequence photographs of the simulation of the Gemini XI extravehicular tasks. (See table III for description.) L-69-1272

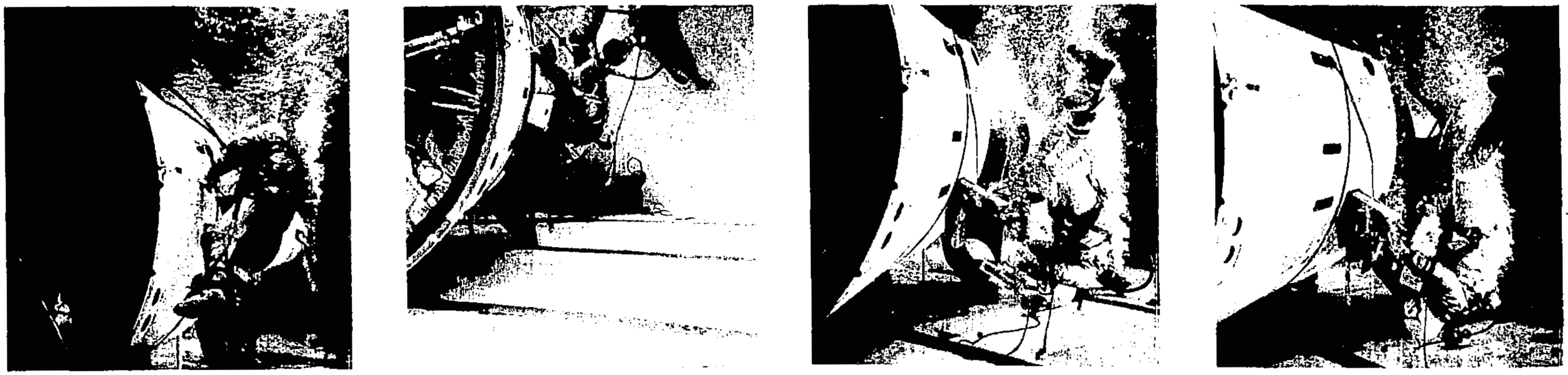


(i) (j) (k) (l)

(m) (n) (o) (p)

Figure 11.- Continued.

L-69-1273



(q) (r) (s) (t)

Without body restraints

(u) (v) (w) (x)

With leg restraint

Figure 11.- Concluded.

L-69-1274

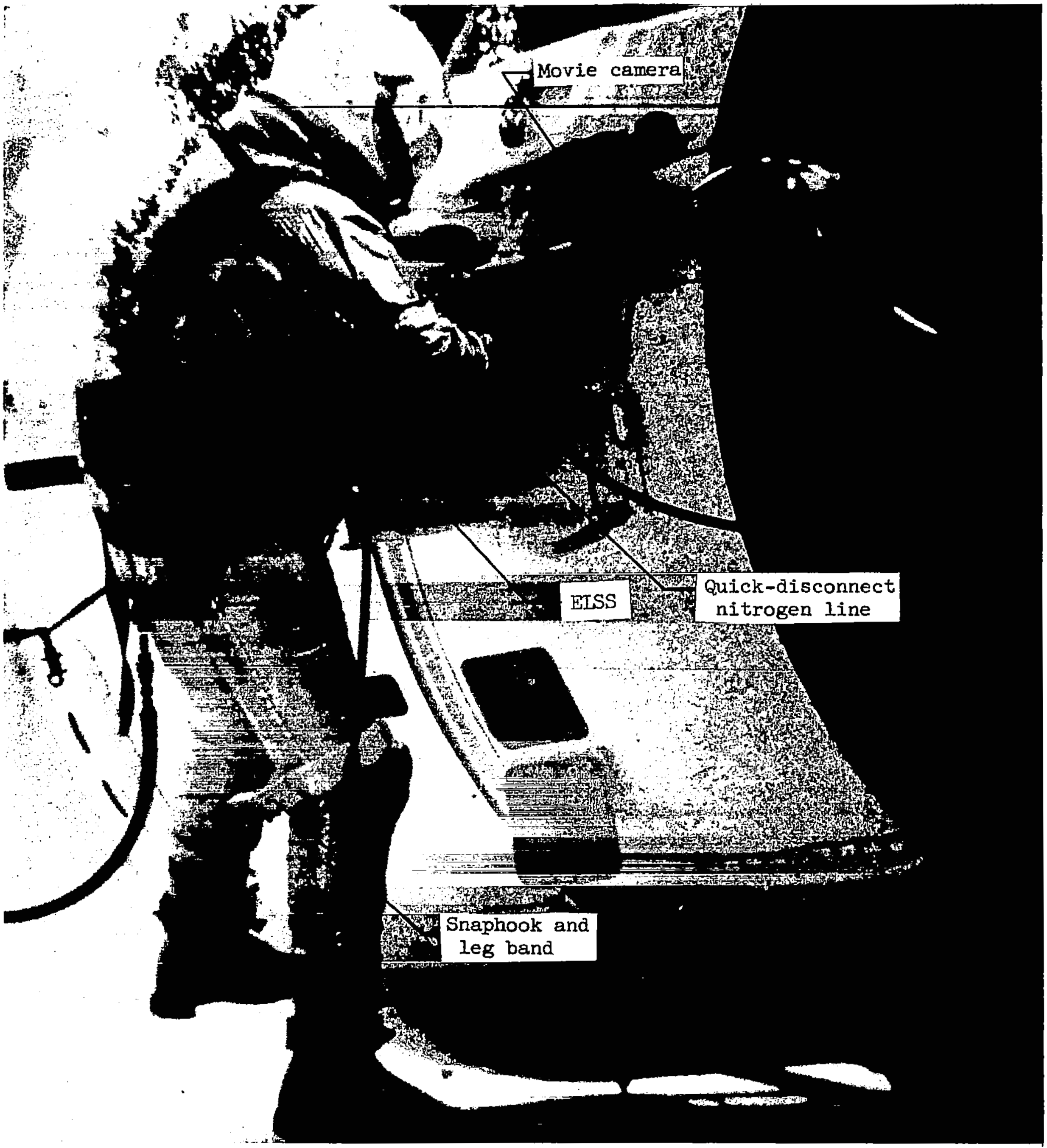


Figure 12.- Photograph of the neutrally buoyant test subject during the Gemini XI simulations. L-69-1275

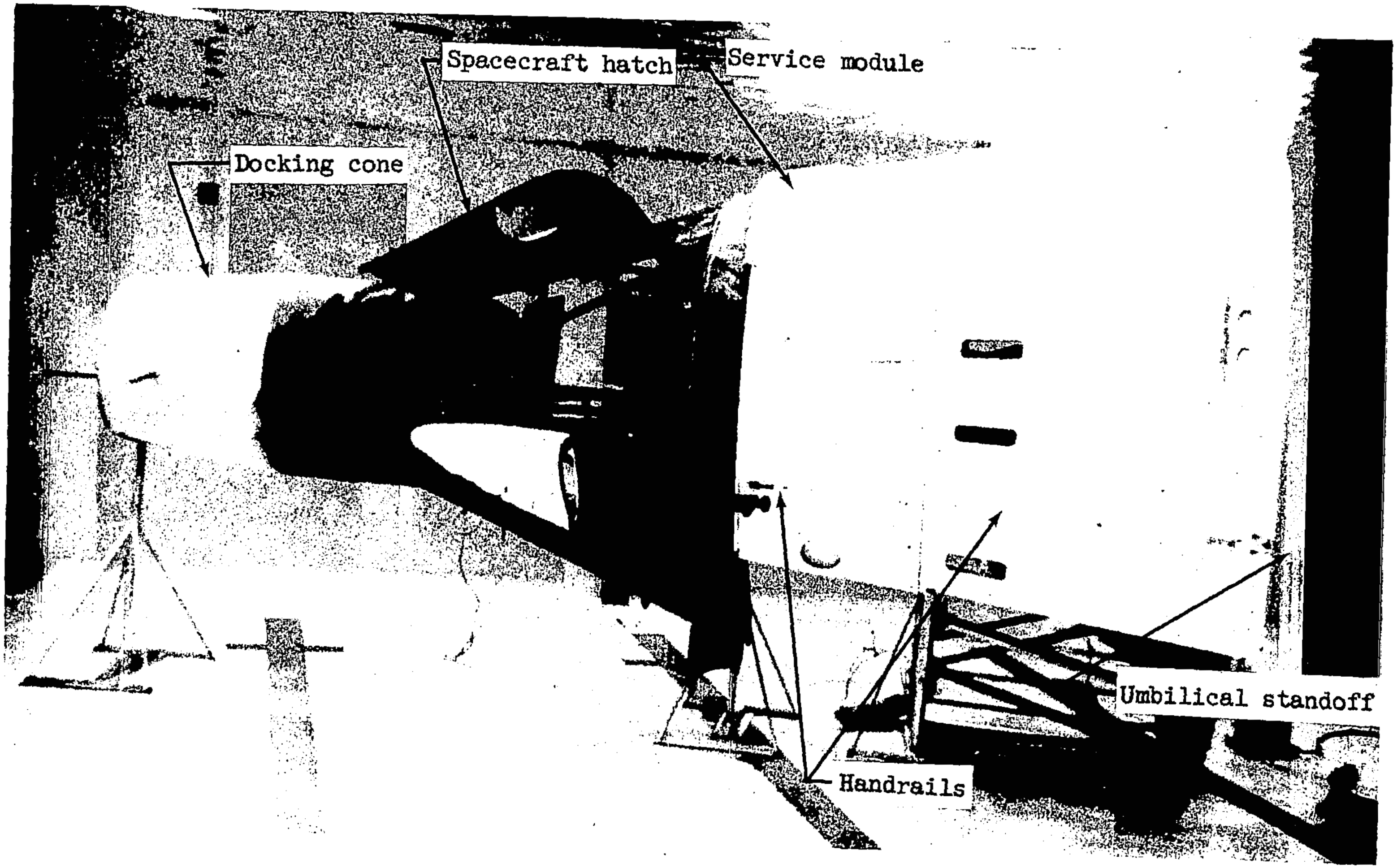


Figure 13.- Mockup for the Gemini XII simulations.

L-69-1276

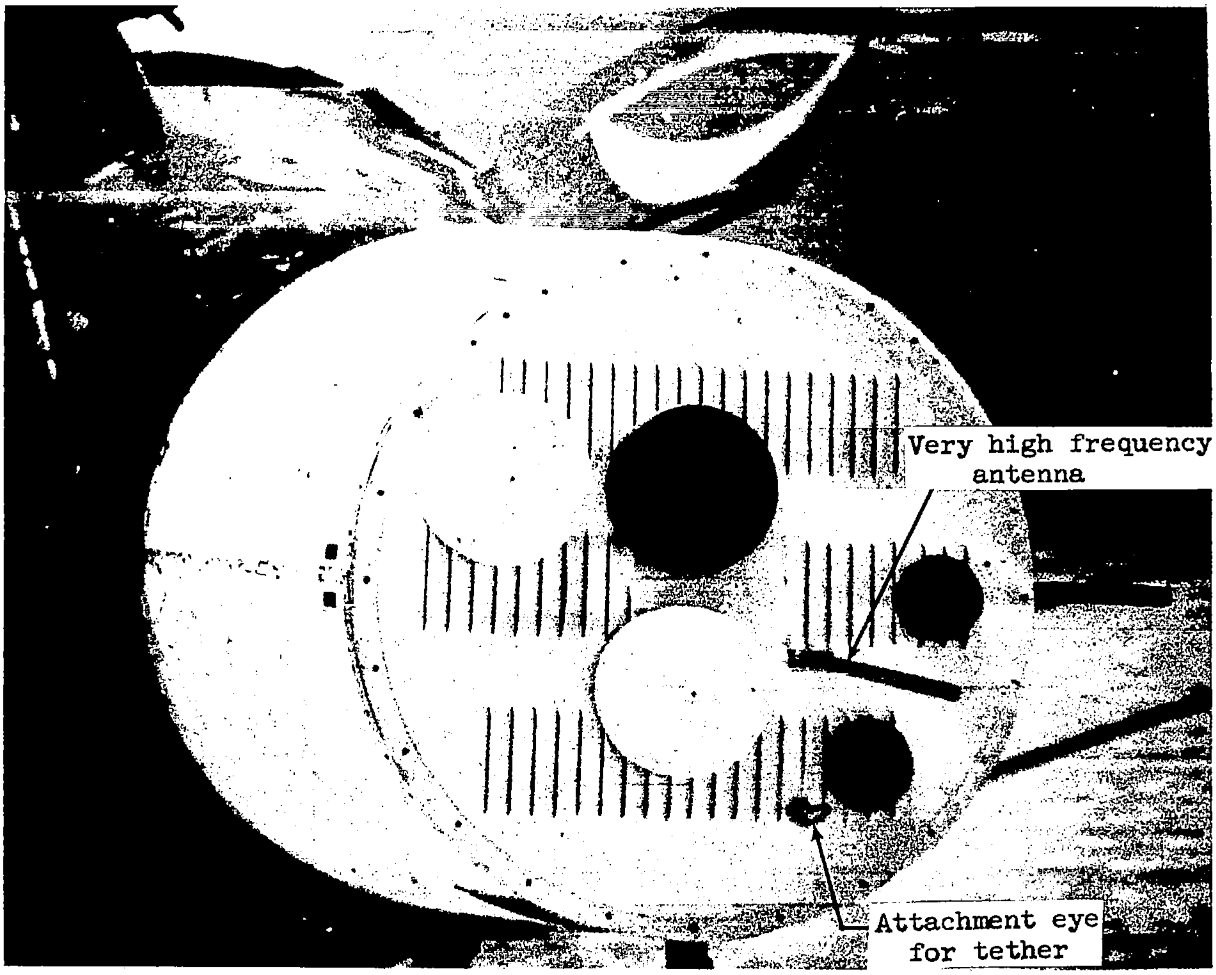
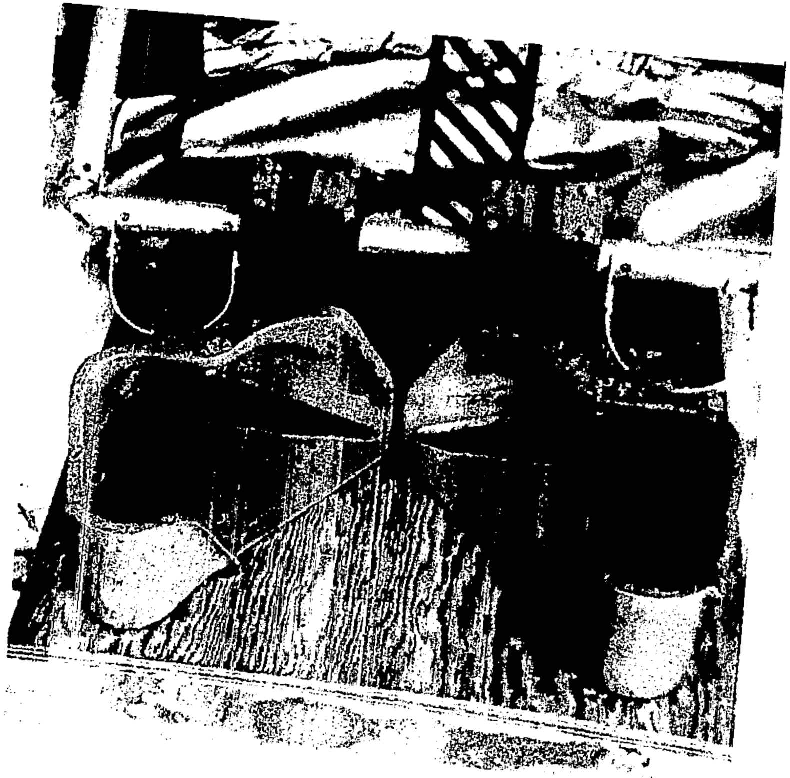


Figure 14.- Photograph of capsule nose showing modifications. L-69-1277



(a) Original foot restraints.

(b) Refined foot restraints.

Figure 15.- Foot restraints for Gemini XII simulations.

L-69-1278

Figure 16.- Test subject placing feet in foot restraints. L-69-1279

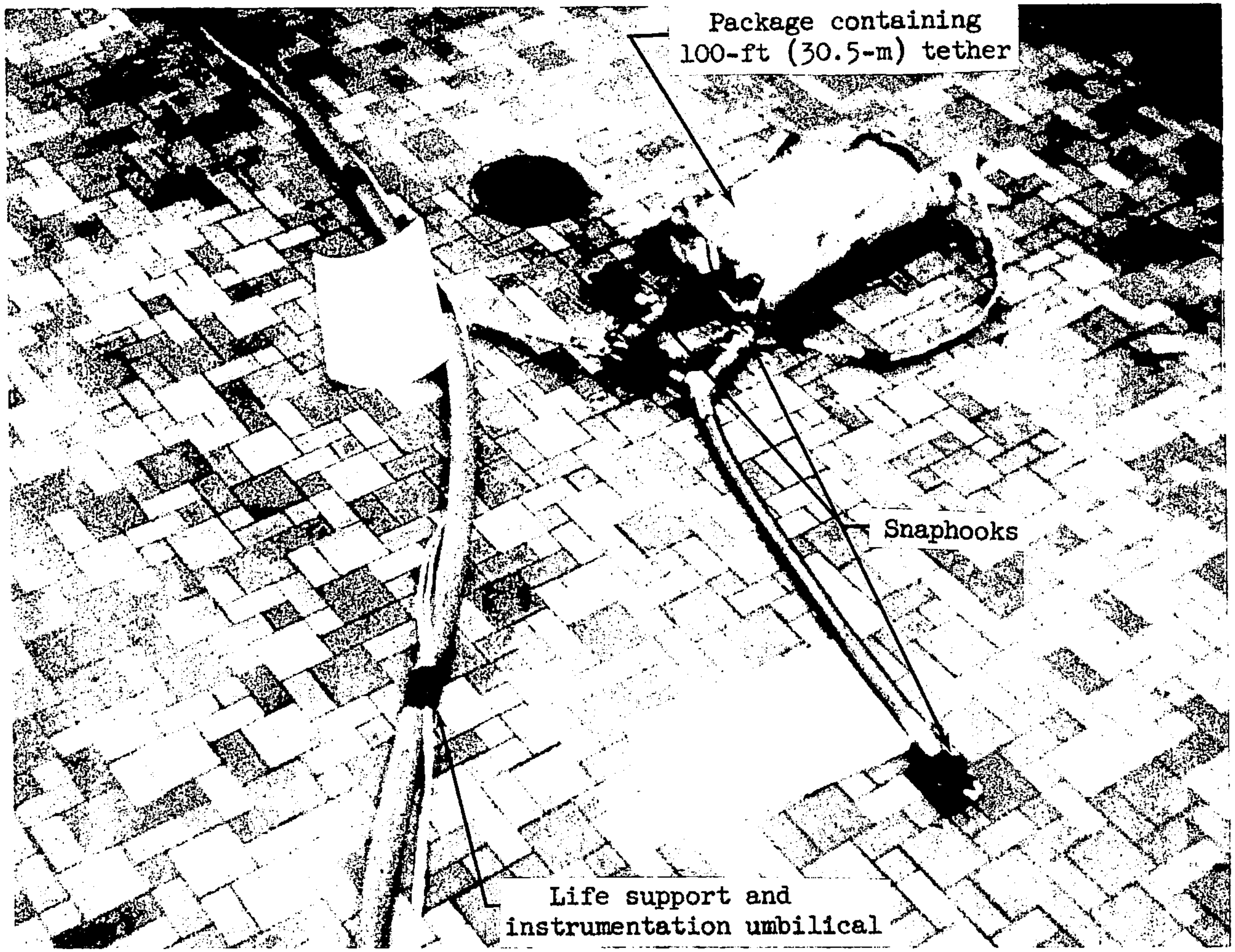
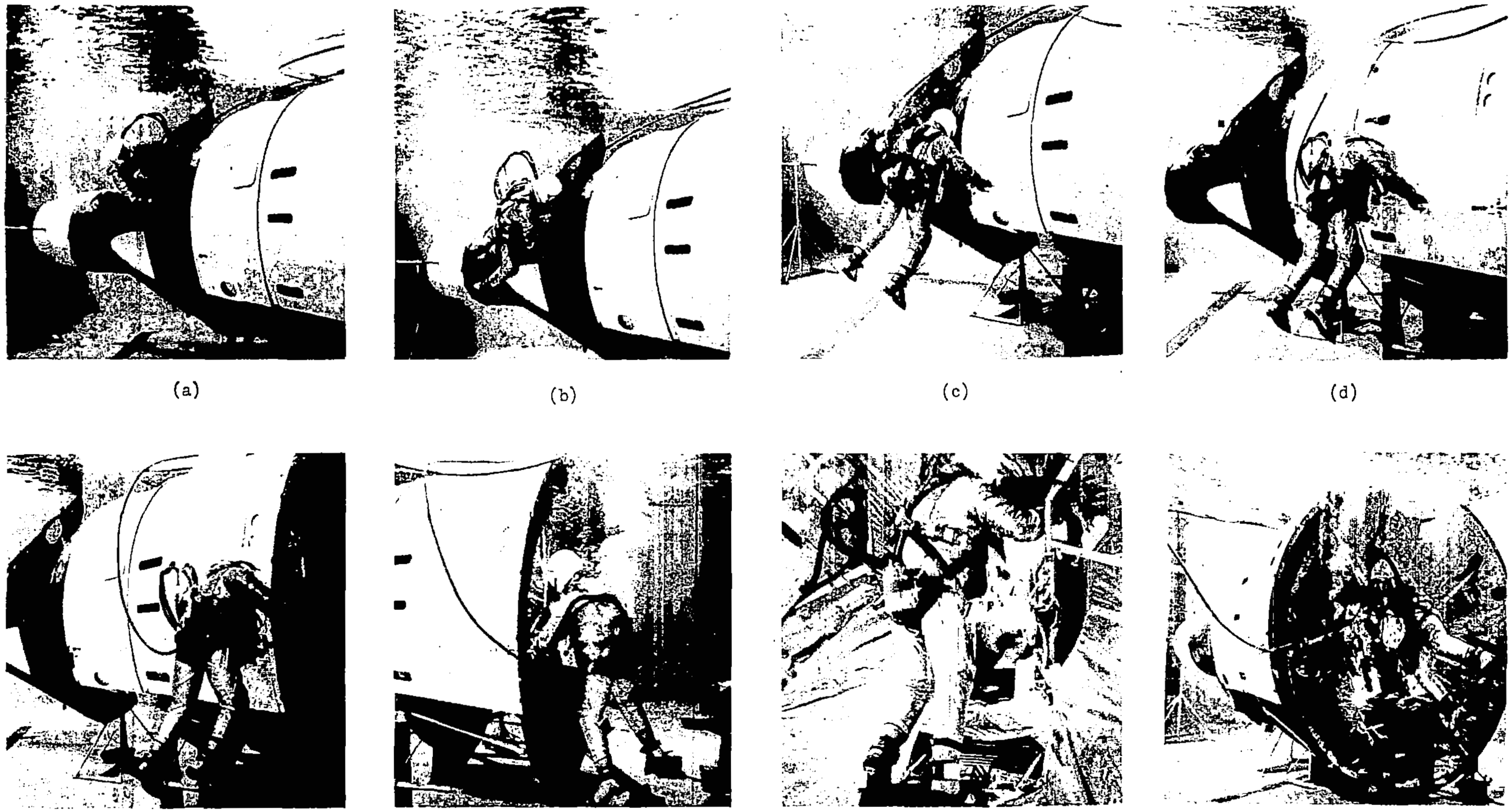


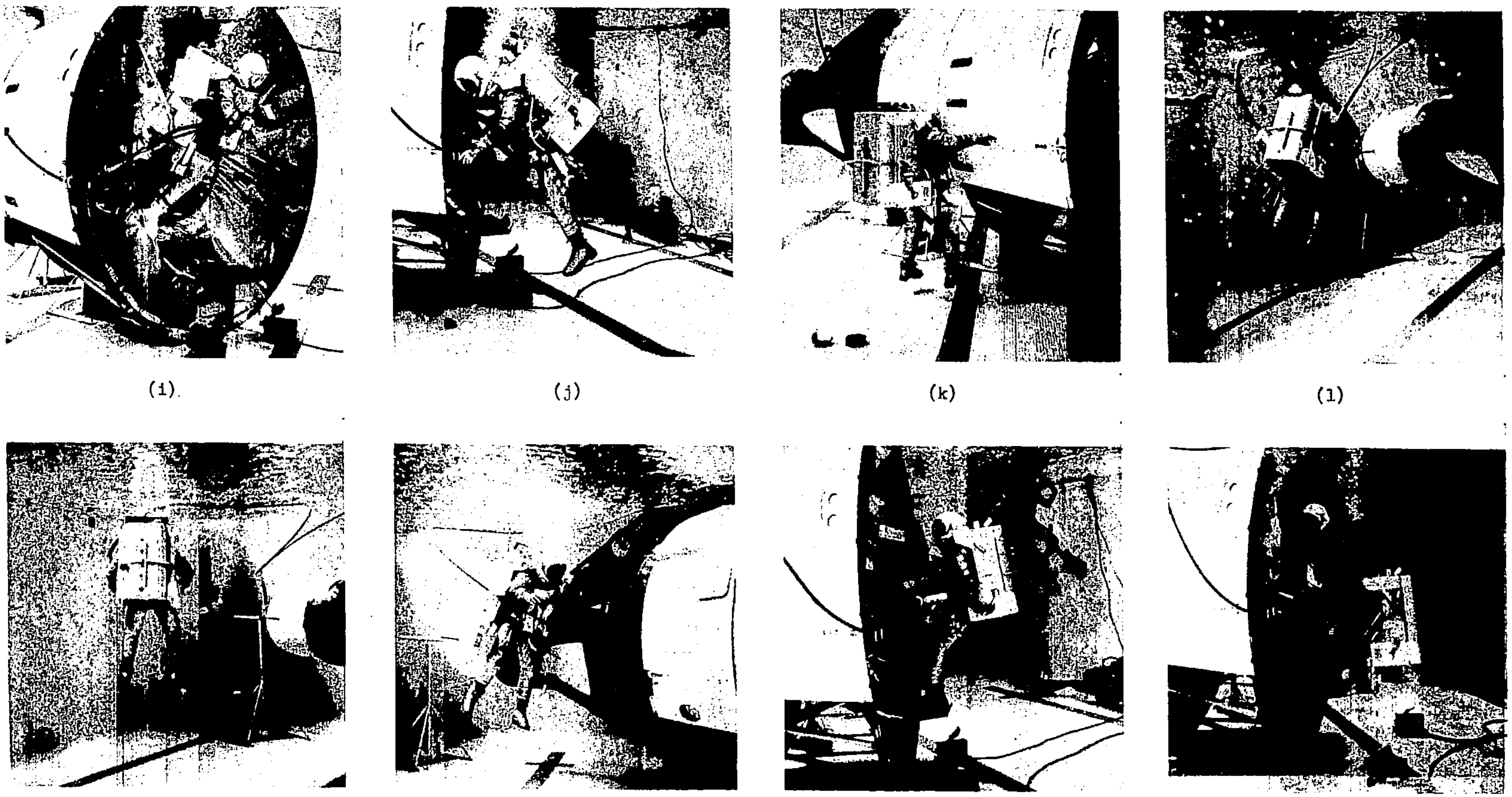
Figure 17.- Tether package and associated hardware to be attached to front of Gemini XII spacecraft during EVA. L-69-1280



(a) (b) (c) (d)

(e) (f) (g) (h)

Figure 18.- Sequence photographs of the early Gemini XII simulations. (See table IV for description.) L-69-1281



(i) (j) (k) (l)

(m) (n) (o) (p)

Figure 18.- Concluded.

L-69-1282

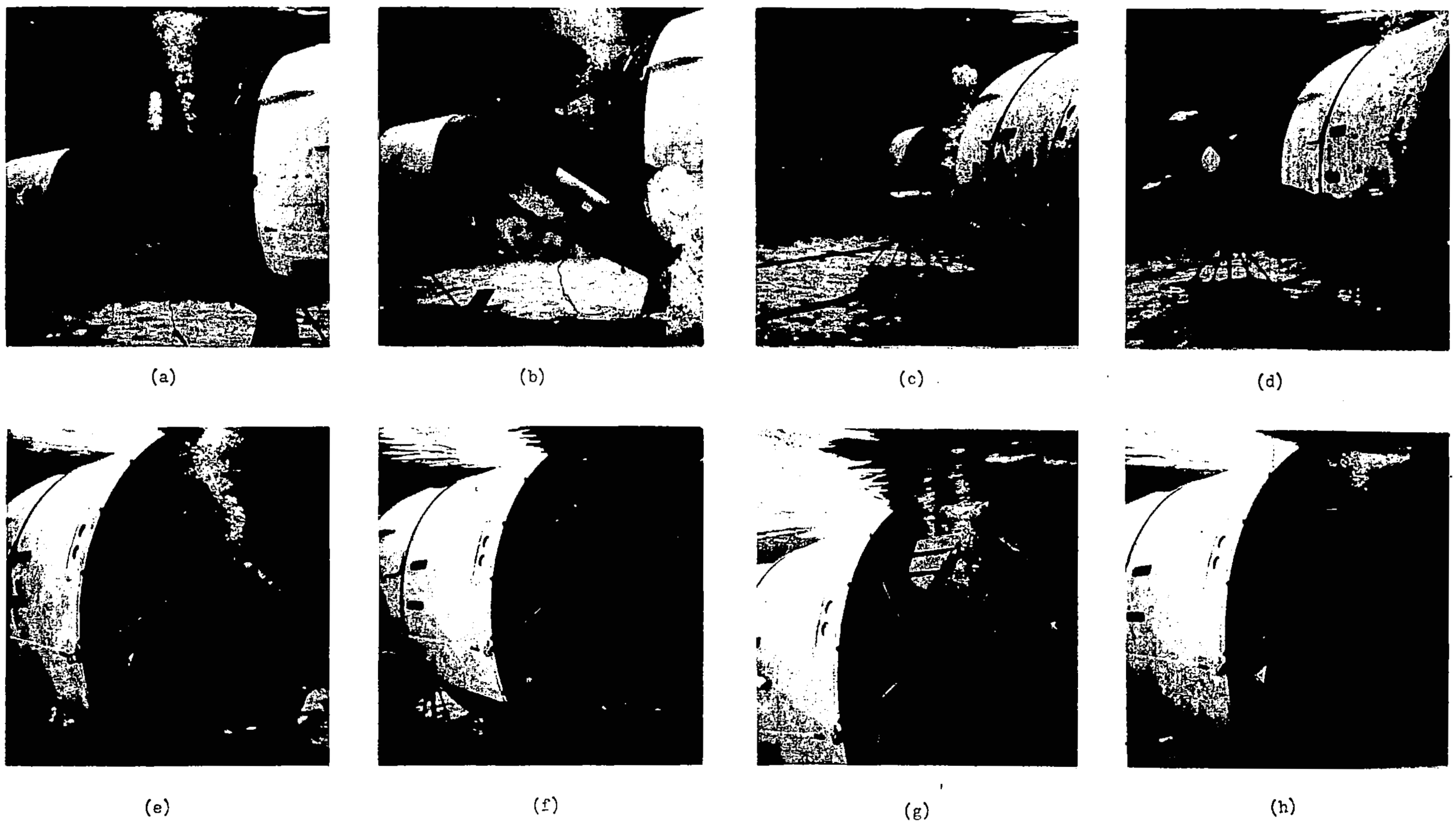
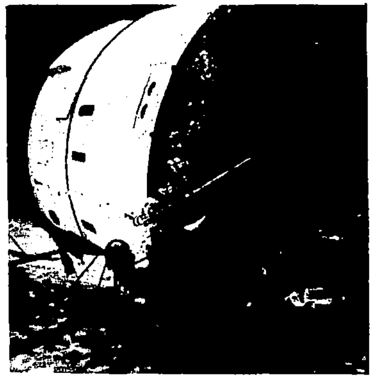
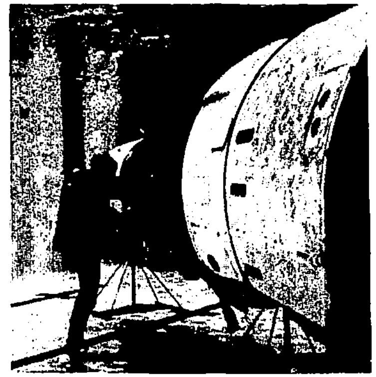


Figure 19.- Sequence photographs of Astronaut Aldrin examining EVA procedures in the scuba mode. L-69-1283

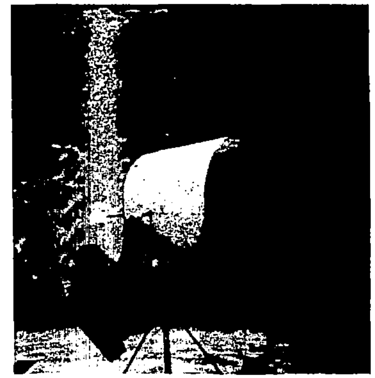
(i)



(j)



(k)

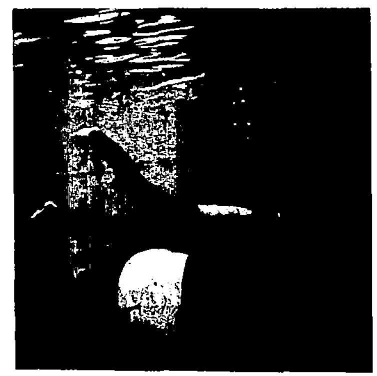


(l)

(m)

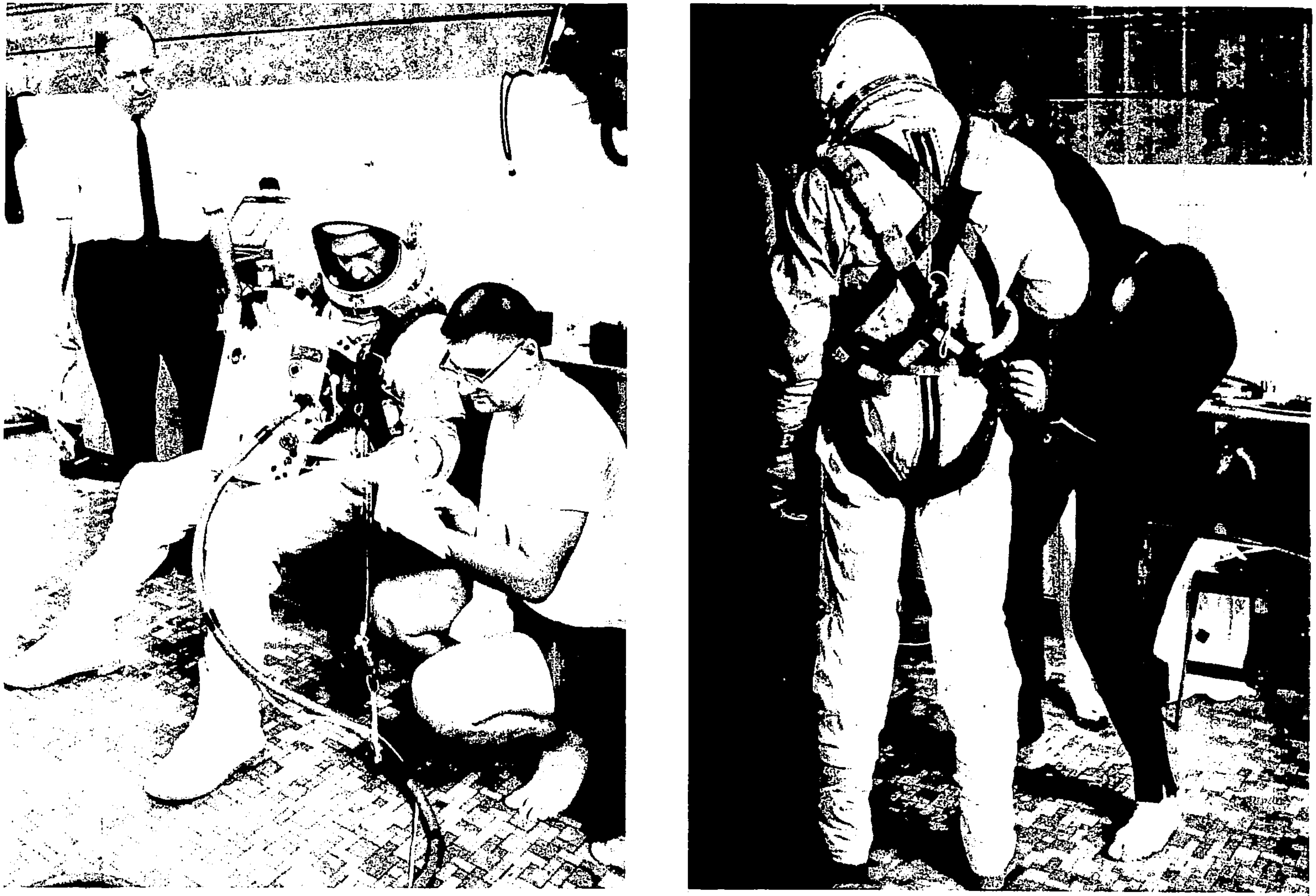
(n)

(o)



(p)

Figure 19.- Concluded. L-69-1284

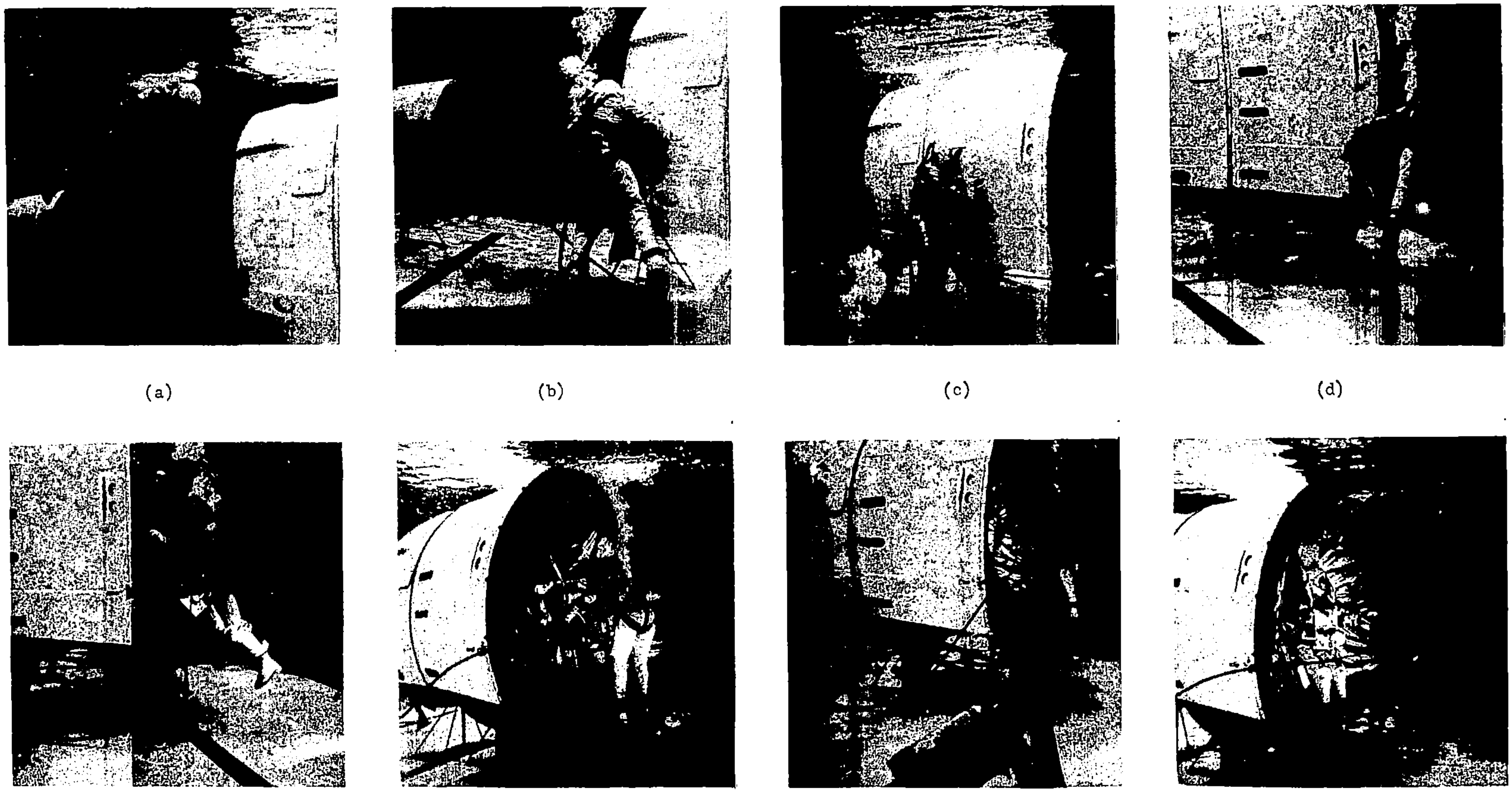


(a) Reviewing checklist.

(b) Fitting ballast weights.

Figure 20.- Astronaut Aldrin preparing for underwater simulations.

L-69-1285

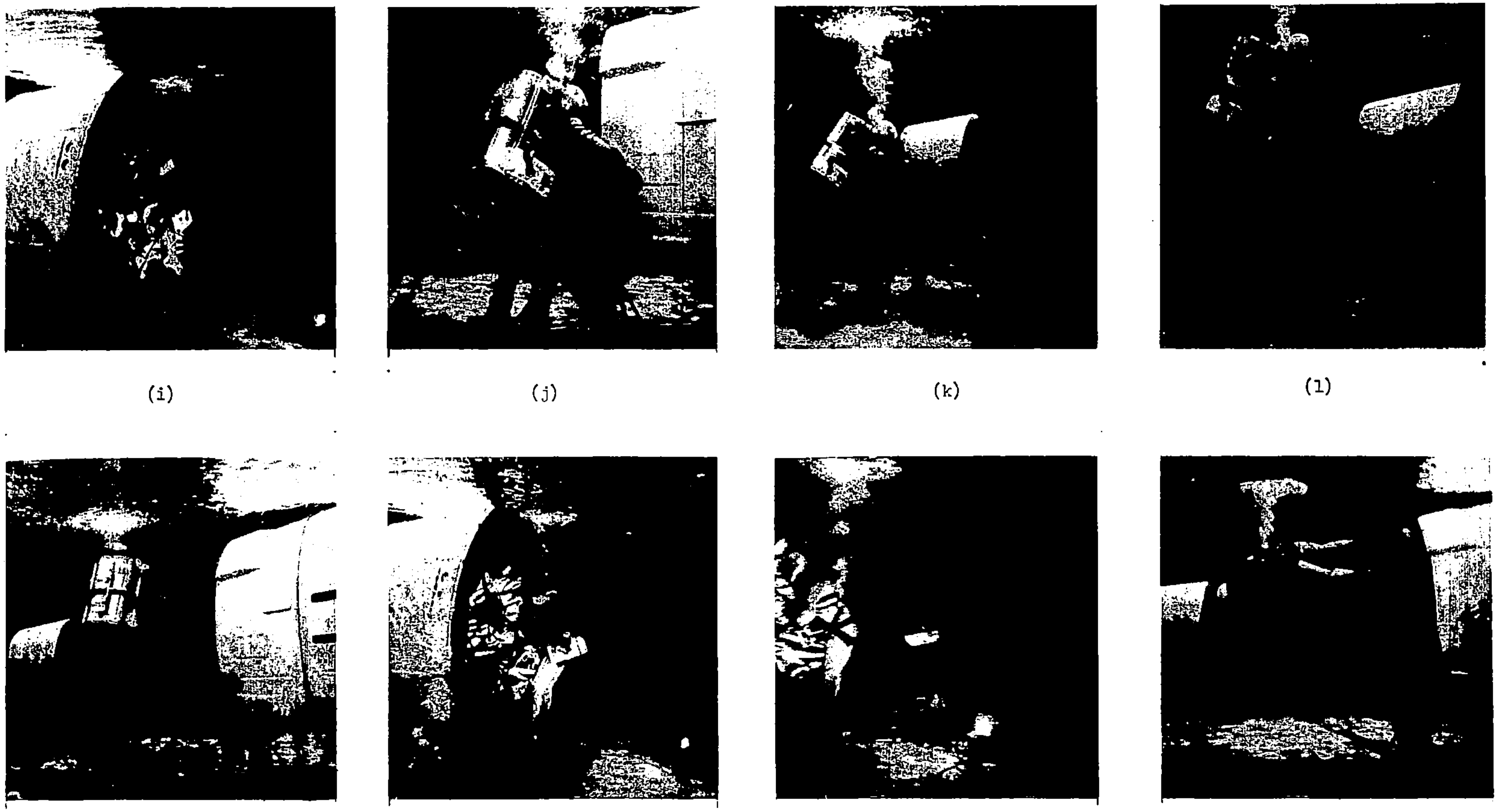


(a) (b) (c) (d)

(e) (f) (g) (h)

L-69-1286

Figure 21.- Sequence photographs of Astronaut Aldrin rehersing the early Gemini XII procedures in the pressure-suit mode. (See table V for description.)



(i) (j) (k) (l)

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Figure 21.- Concluded.

L-69-1287

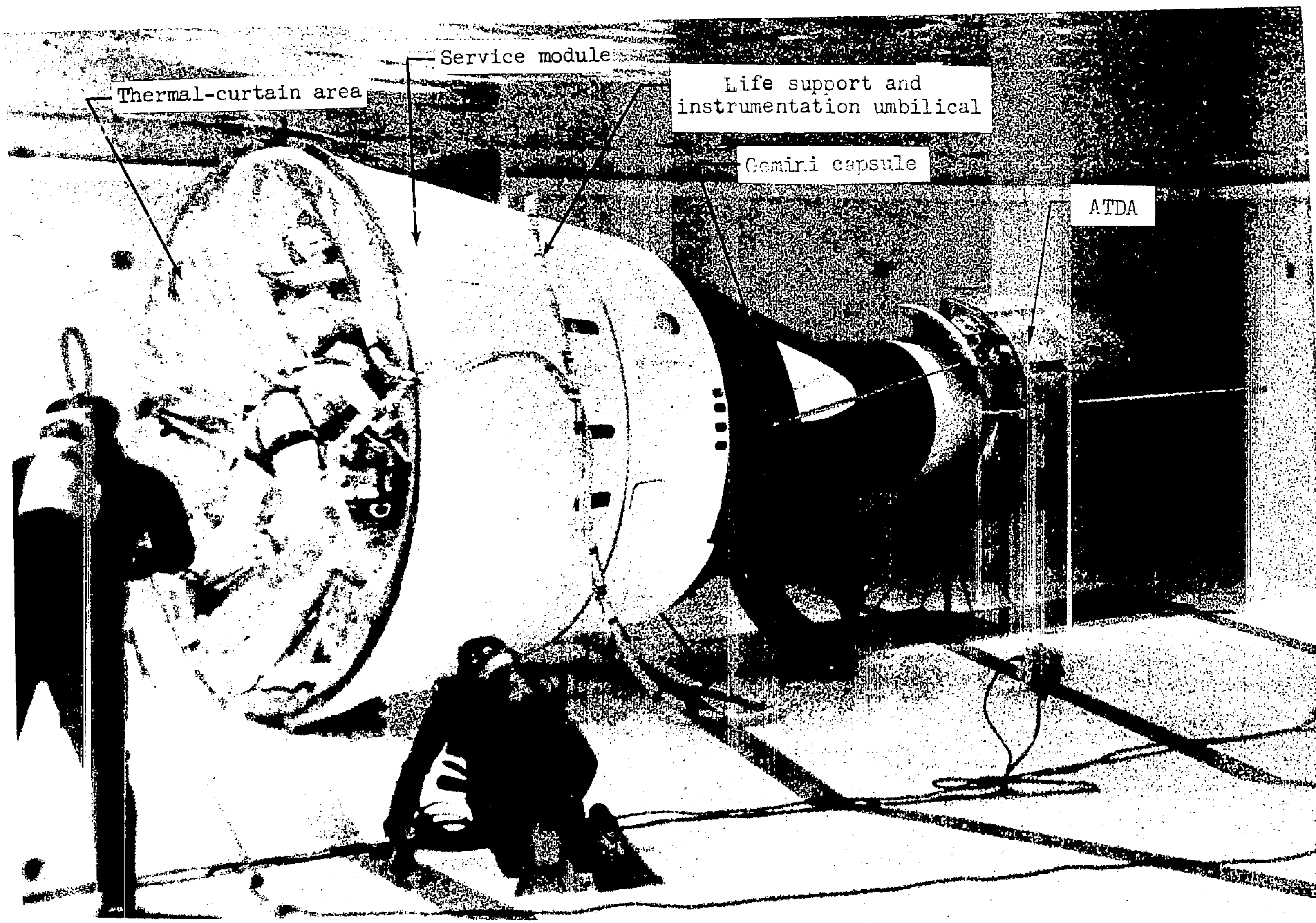


Figure 22.- Mockup used in Gemini XII simulations beginning in October 1966.

L-69-1288

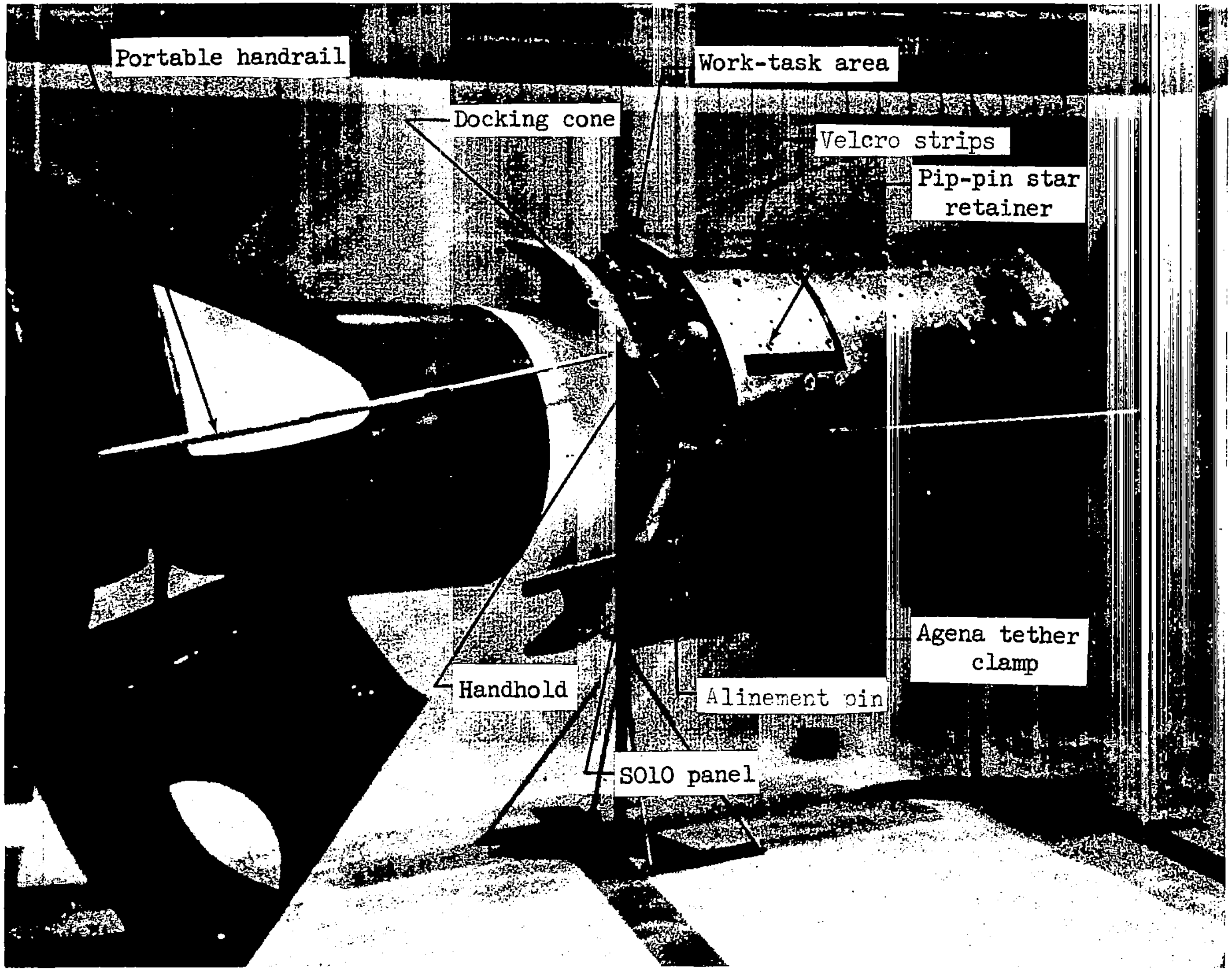


Figure 23.- ATDA mockup and associated hardware.

L-69-1289

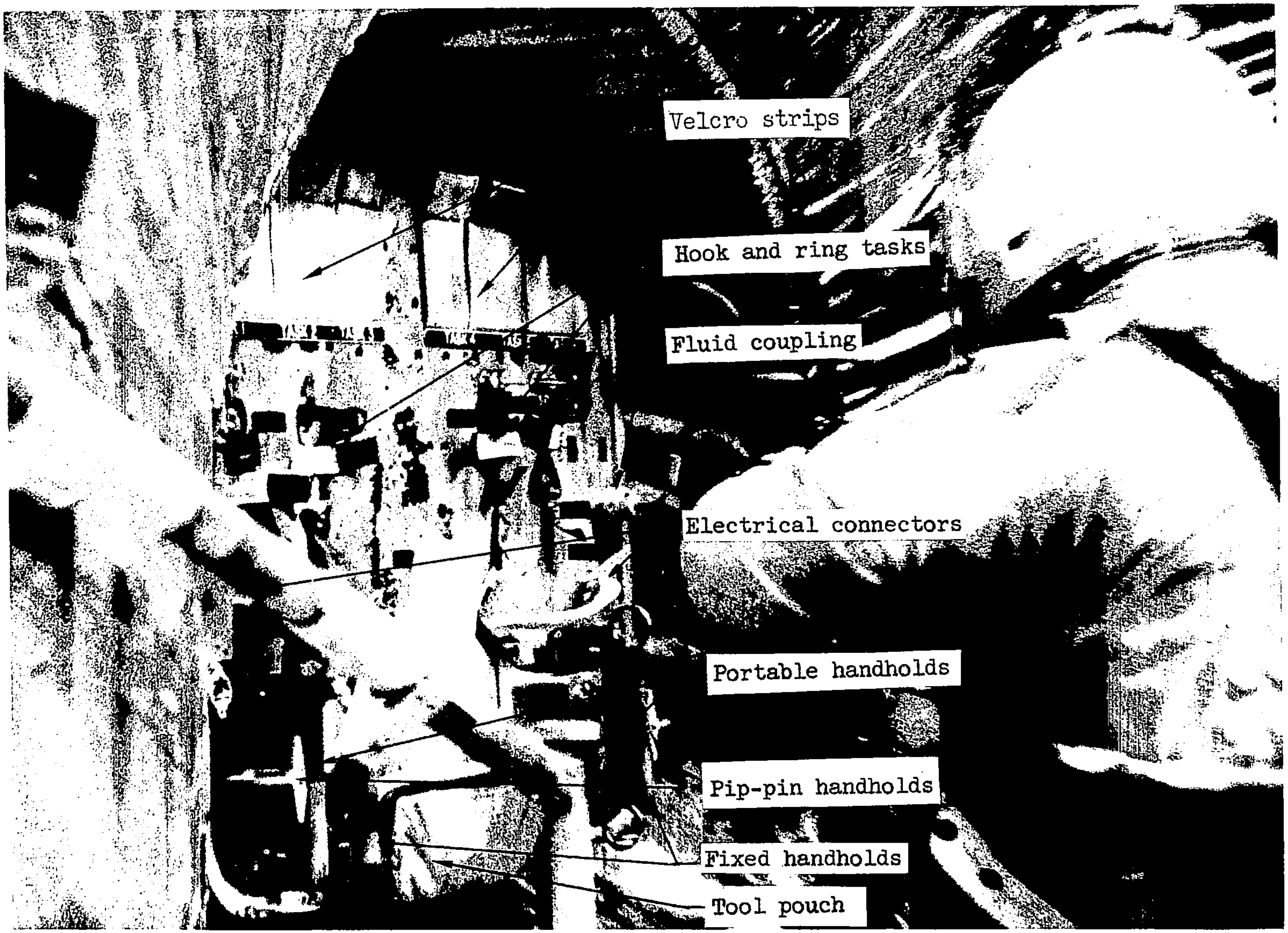
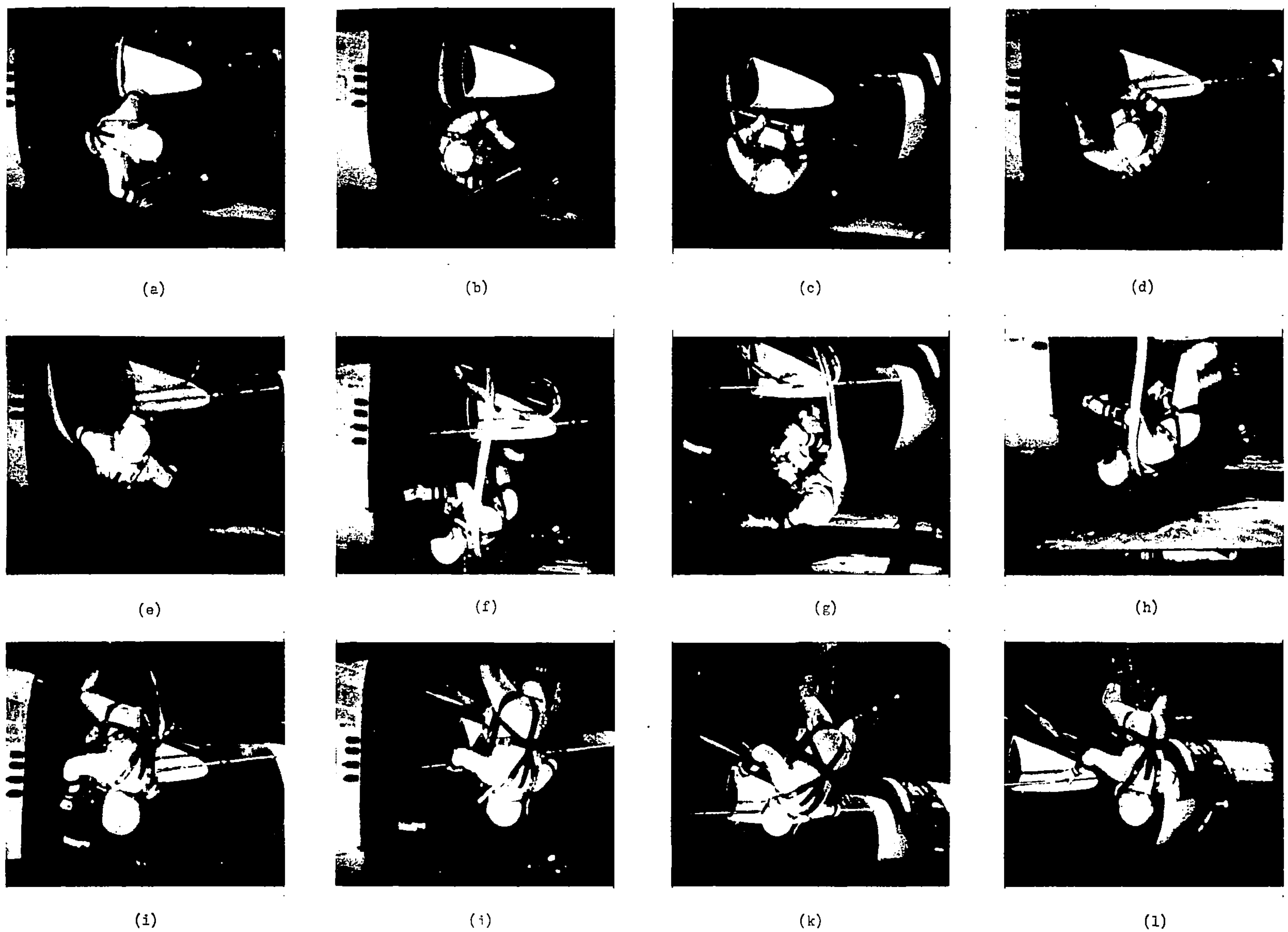


Figure 24.- Task panel in thermal-curtain area.

L-69-1290



L-69-1291

Figure 25.- Sequence photographs of events during the final neutral-buoyancy training simulation for the Gemini XII mission. (See table VI for description.)

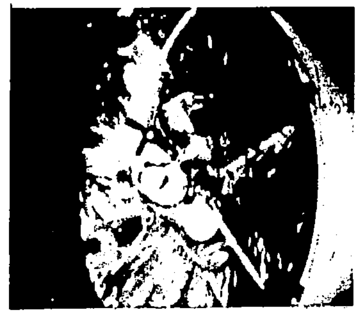
Figure 25.- Continued.

L-69-1292

(y)

(z)

(aa)



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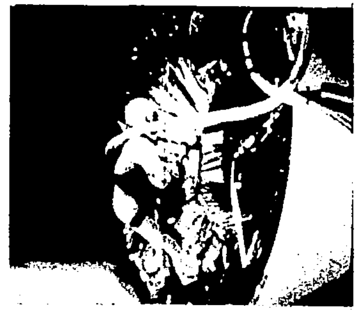
(ae)



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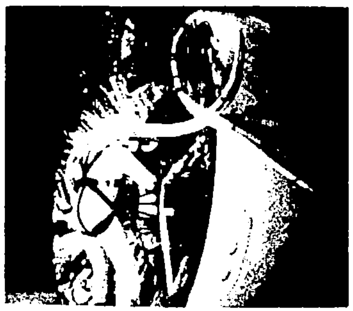
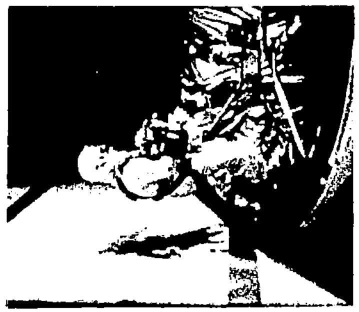


(ag)

(ah)



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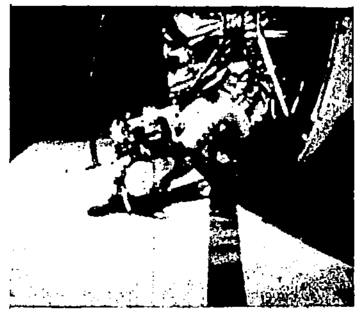

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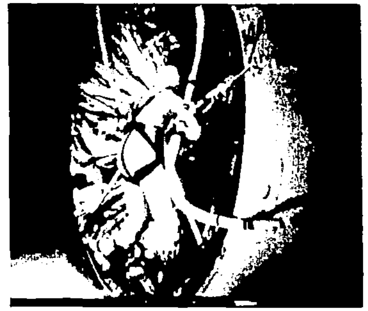
Figure 25.- Continued. L-69-1293

(ak)

(al)



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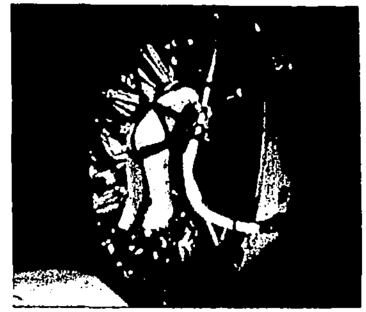

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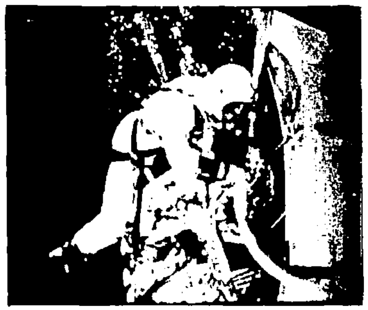

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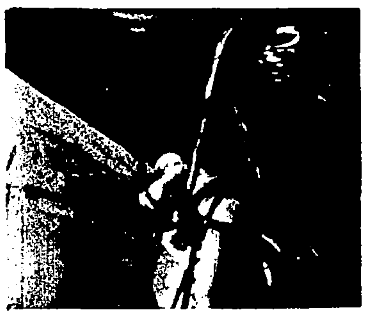

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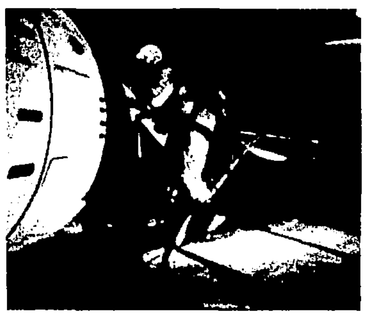

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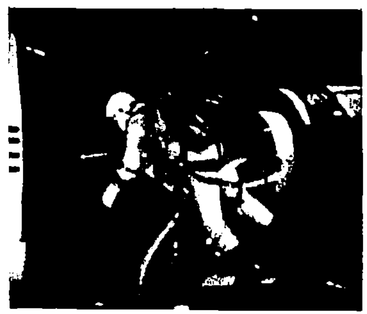

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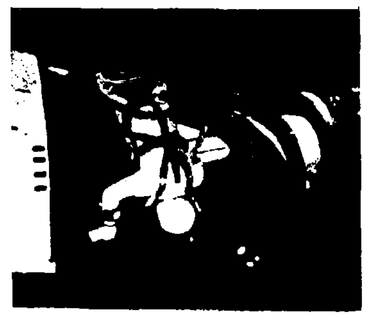

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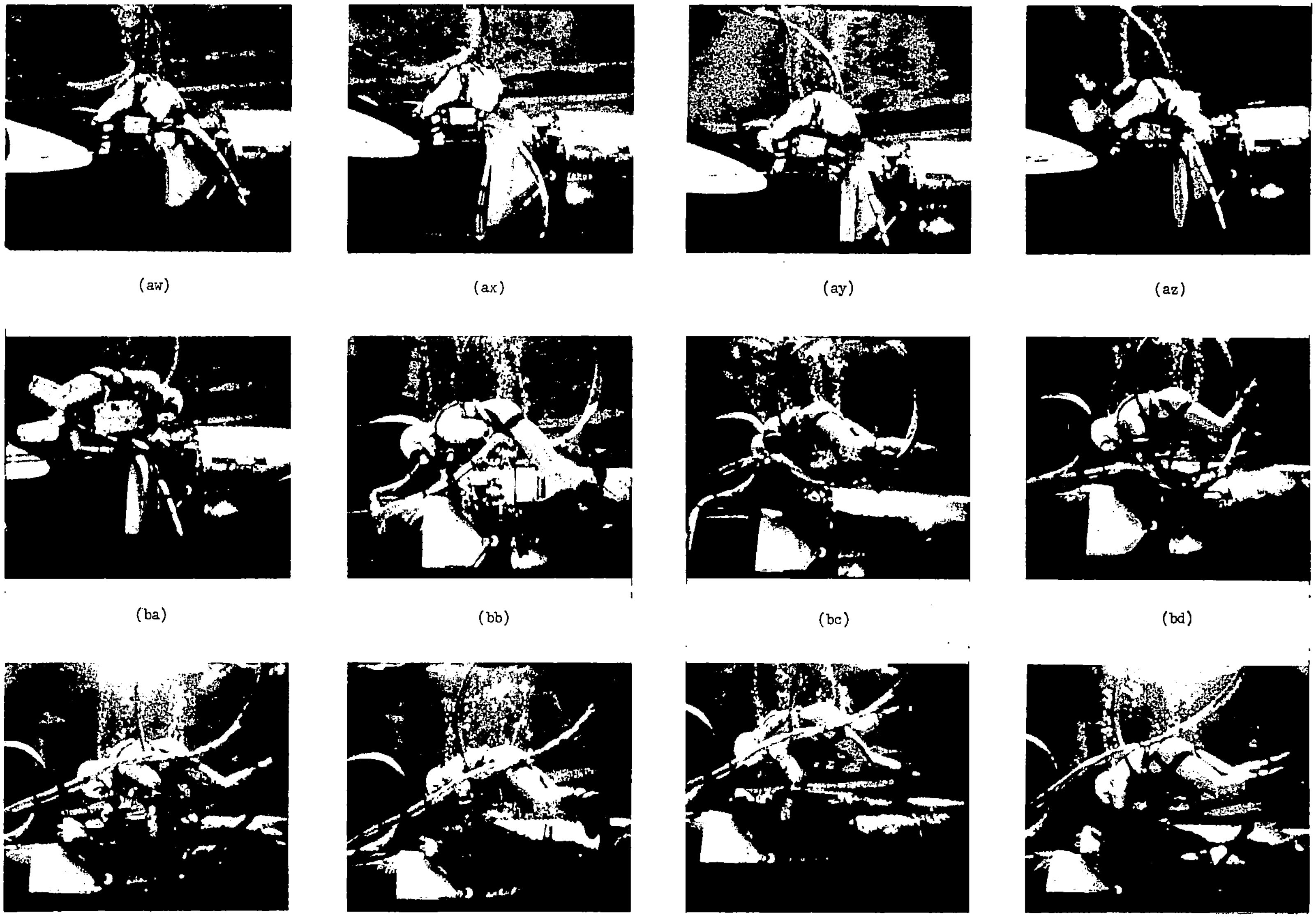
Figure 25.- Continued. L-69-1294



(aw) (ax) (ay) (az)

(ba) (bb) (bc) (bd)

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Figure 25.- Continued.

L-69-1295

(bi)

(bj)

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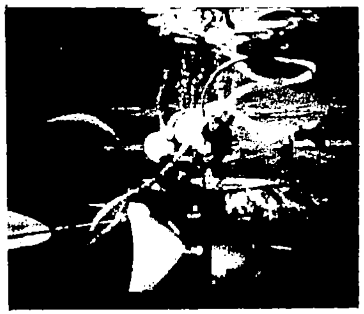

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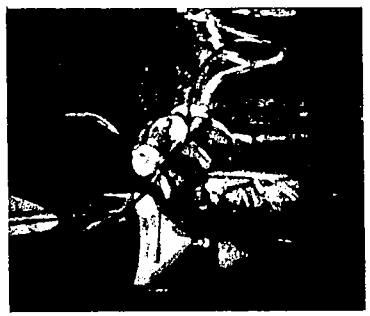

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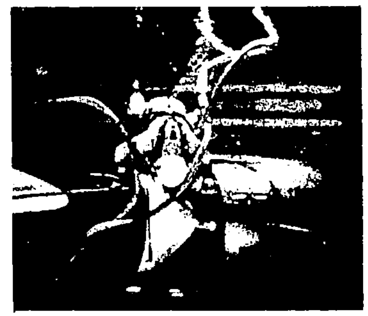

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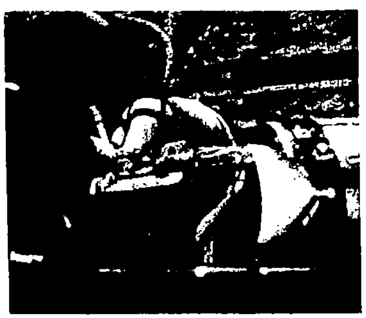

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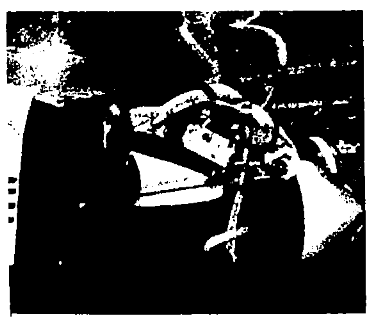

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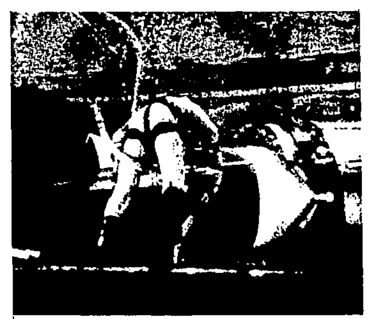

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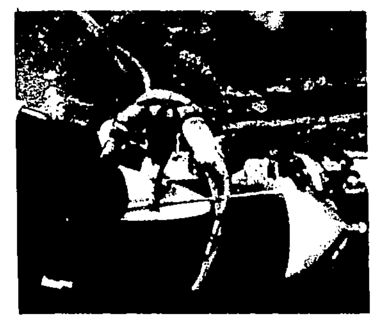

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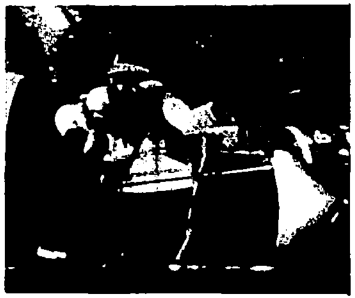
Figure 25.- Continued.

L-69-1296



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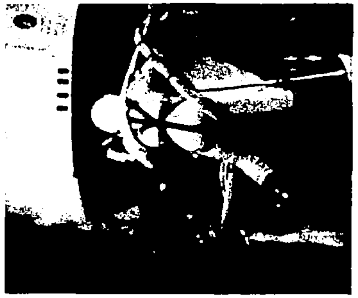

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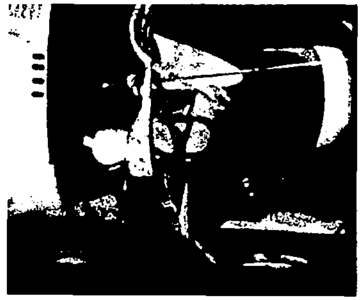

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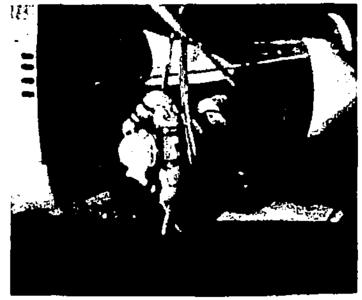

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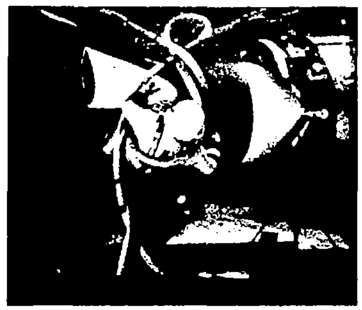

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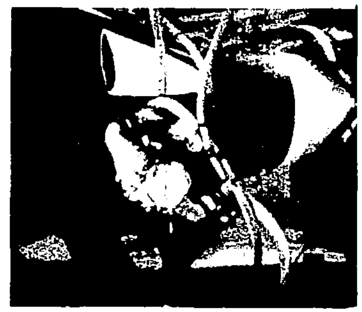

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Figure 25.- Concluded.

L-69-1297

Figure 26.- Astronaut transferring from the Gemini XII to the ATDA by means of the portable telescoping handrail. L-69-1298

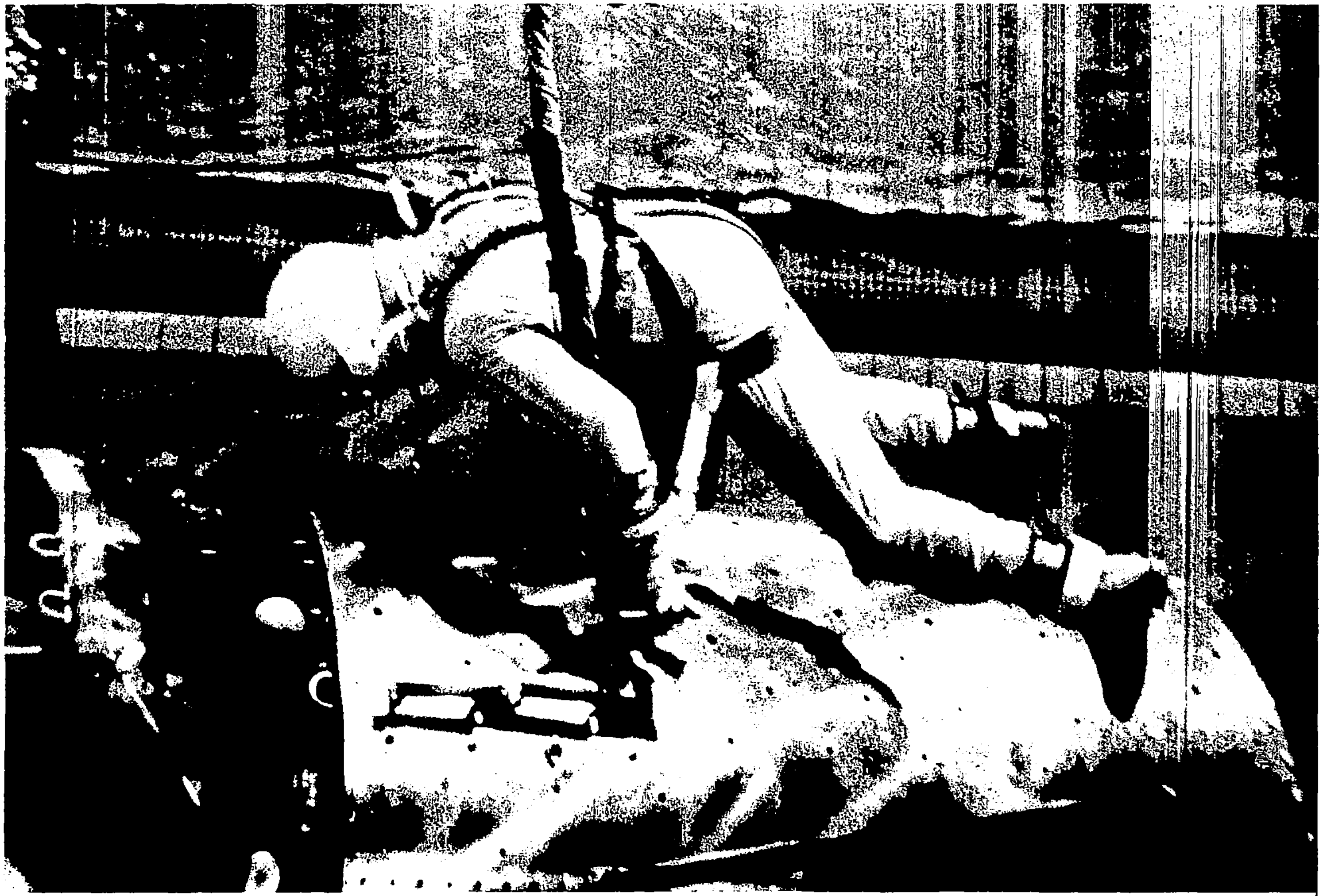

Figure 27.- Astronaut attaching waist tether to the mockup. L-69-1299

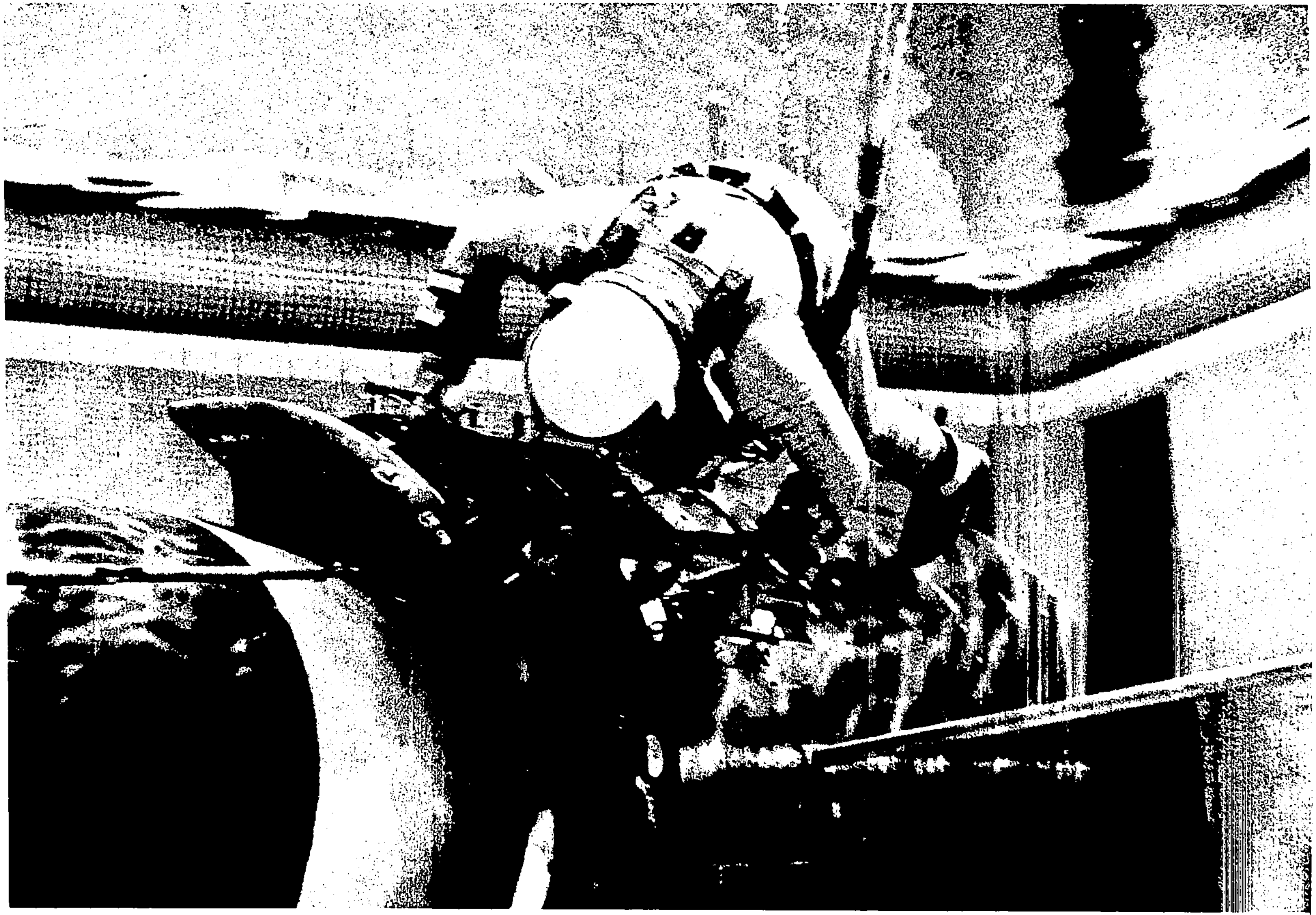

Figure 28.- Astronaut tightening a bolt with a torque wrench while he was attached by the waist tethers. L-69-1300

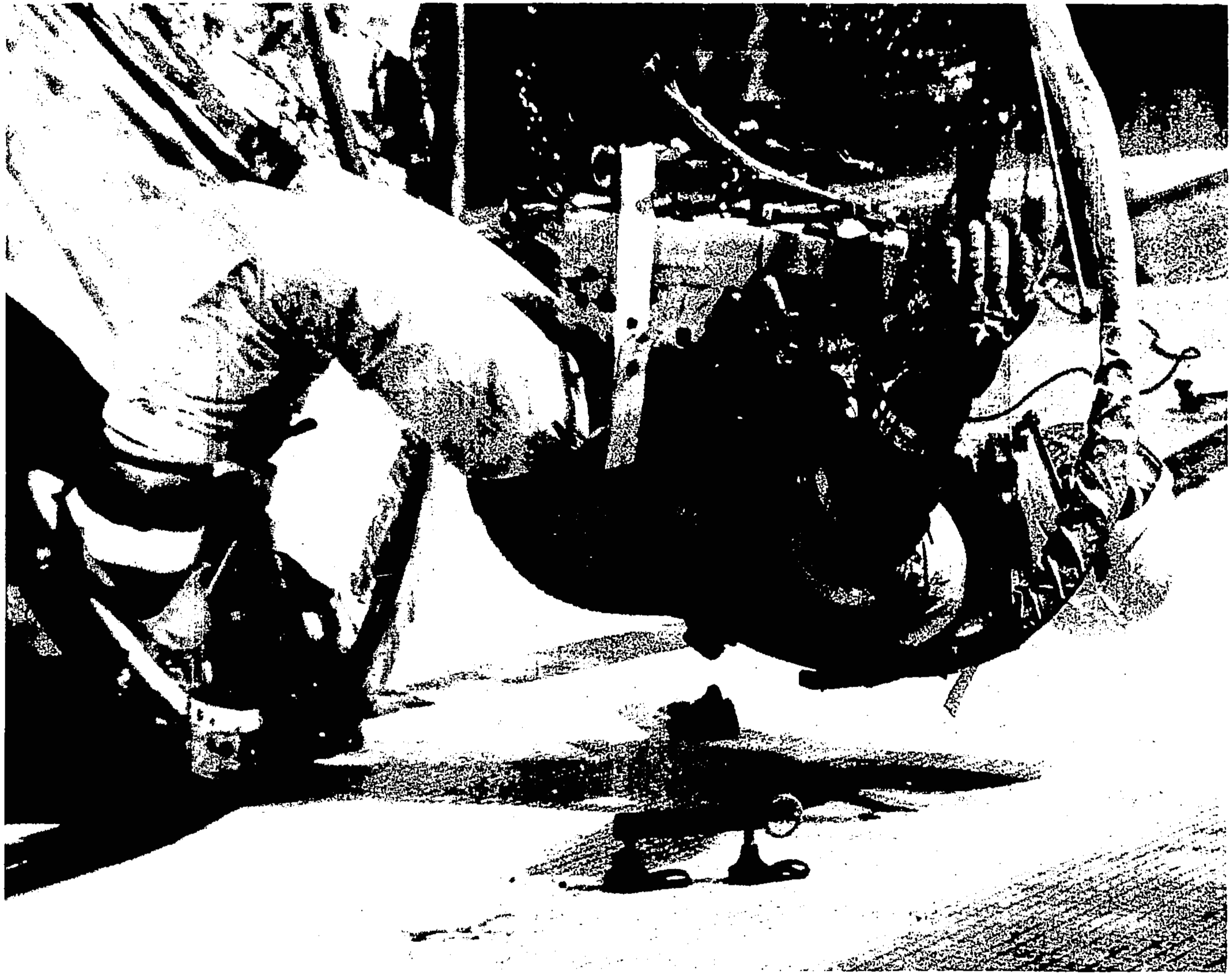

Figure 29.- Astronaut testing maneuverability while using foot restraints. L-69-1301

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